

PART F5

FAULT TREE ANALYSIS - APOLLO 13 ACCIDENT*

INTRODUCTION

This report contains a fault tree analysis of the applicable portions of the electrical power and cryogenic systems involved in the Apollo 13 incident. It was prepared by the Boeing Company under the direction of MSC and at the request of the Apollo 13 Review Board.

PURPOSE

The purpose of this analysis is to identify potential causes that could lead to the loss of the SM main bus power, to show their logical associations, and to categorize them as being true or false for the Apollo 13 incident based upon available data, analyses, and tests. The prime emphasis is to identify the initiating cause, and secondarily, the sequence of events leading to the loss of SM main bus power.

SCOPE

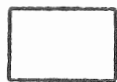
This fault tree identified the applicable ECS/cryogenic system hardware and potential causes, down to the component or groups of components level. The logical association of the potential causes is shown graphically and is developed tracing the system functions backwards. Each potential cause is categorized as being true or false where flight data, ground tests, technical analyses, and/or engineering judgment provide sufficient rationale. The main thread to determine the initiating cause is identified in the fault tree. The tree does not include unrelated or secondary effects of the failure (i.e., quantity gage malfunction, panel blow-off, fire in the service module).

Pages F-108 through F-114 provide information on symbology, terminology, abbreviations, references, and schematics for reference during review of the fault tree. Page F-111 identifies what pages of the fault tree are associated with the various segments of the system. Page F-115 pictorially depicts the required layout of the pages of the fault tree to provide an overview of the complete system.

*Extracted from "Fault Tree Analysis - Apollo 13 Incident," dated June 5, 1970, under Contract NAS 9-10364 - Task Item 9.0, for MSC Apollo 13 Review Board, Action Item 35.

DESCRIPTION OF FAULT TREE DEVELOPMENT PROCESS:

BEGINNING FROM THE DEFINED UNDESIRED EVENT, "FUEL CELL POWER NOT AVAILABLE ON SM BUSES", THE CAUSATIVE FACTORS HAVE BEEN SHOWN BY MEANS OF LOGIC DIAGRAMMING. GIVEN THAT A SPECIFIED EVENT CAN OCCUR, ALL POSSIBLE CAUSES FOR THAT EVENT ARE ARRAYED UNDER IT. IT IS IMPORTANT TO NOTE THAT THIS LISTING INCLUDES ALL POSSIBLE WAYS IN WHICH THE EVENT CAN OCCUR. NEXT, THE RELATIONSHIP OF THESE CAUSATIVE FACTORS TO ONE ANOTHER AND TO THE ULTIMATE EVENT IS EVALUATED AND A DETERMINATION AS TO WHETHER THE DEFINED CAUSES ARE MUTUALLY INDEPENDENT, OR ARE REQUIRED TO COEXIST, IS MADE. THE SYMBOLOGY EMPLOYED TO ILLUSTRATE THE THOUGHT PROCESS IS AS FOLLOWS:



FAILURE/CAUSE STATEMENT - FAILURES ARE SHOWN WITHIN THE LOGIC BLOCKS - TRUE AND FALSE STATEMENTS AND RATIONALE ARE ADJACENT TO THE APPLICABLE BLOCKS.



"OR" GATE - THOSE CAUSES WHICH ARE CAPABLE, INDEPENDENTLY, OF BRINGING ABOUT THE UNDESIRED EVENT ARE ARRAYED HORIZONTALLY BELOW THE "OR" SYMBOLS.



"AND" GATE - THOSE CAUSES WHICH MUST COEXIST ARE ARRAYED HORIZONTALLY BELOW THE "AND" SYMBOLS.



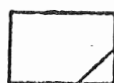
"INHIBIT" GATE - THOSE FACTORS WHICH INTRODUCE ELEMENTS OF CONDITIONAL PROBABILITY, AND WHICH ARE REQUIRED TO COEXIST WITH OTHER CAUSES, ARE DEFINED AS "INHIBIT" FUNCTIONS.



"HOUSE" - THOSE CAUSATIVE FACTORS WHICH ARE NORMALLY EXPECTED TO EXIST, OR TO OCCUR, ARE SHOWN AS "HOUSES".



"DIAMOND" - TERMINATED FOR THIS SUB-BRANCH; FURTHER DEVELOPMENT NOT REQUIRED FOR THIS ANALYSIS.



"CUT CORNER" - INDICATES THIS IS A KEY OR NODAL BLOCK. ANALYSIS OF THESE BLOCKS WAS PERFORMED IN GREATER DEPTH SINCE THEY "CONTROL" SIGNIFICANT PORTIONS OF THE FAULT TREE.

TRUTH STATEMENT CATEGORIZATION:

EACH FAILURE STATEMENT IS REVIEWED TO DETERMINE WHETHER IT IS TRUE OR FALSE. THE TYPE DATA USED TO SUPPORT A STATEMENT BEING TRUE OR FALSE IS IDENTIFIED. IN ADDITION, THE SUPPORTING DATA SOURCES ARE REFERENCED.

CODE KEY

<u>CATEGORY</u>	<u>DATA TYPE</u>
F = FALSE	FD = PER FLIGHT DATA
T = TRUE	A = PER ANALYSIS
	GD = PER GROUND DATA
	EJ = PER ENGINEERING JUDGEMENT
	TE = PER TEST
	SL = SUBORDINATE LOGIC (SUPPORTED BY SUB-TIER LOGIC.)

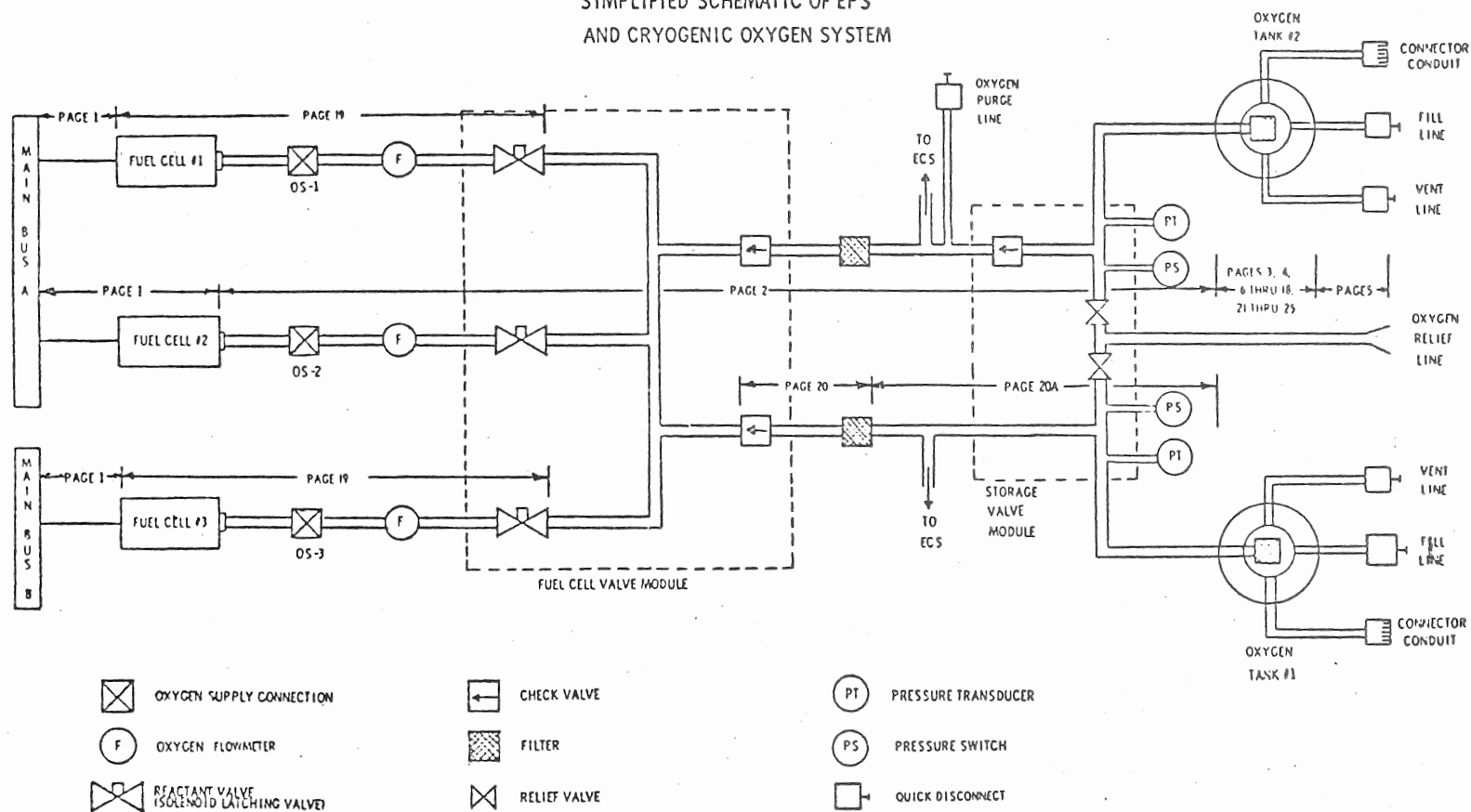
EXAMPLE: F - FD = FALSE PER FLIGHT DATA

REFERENCES:

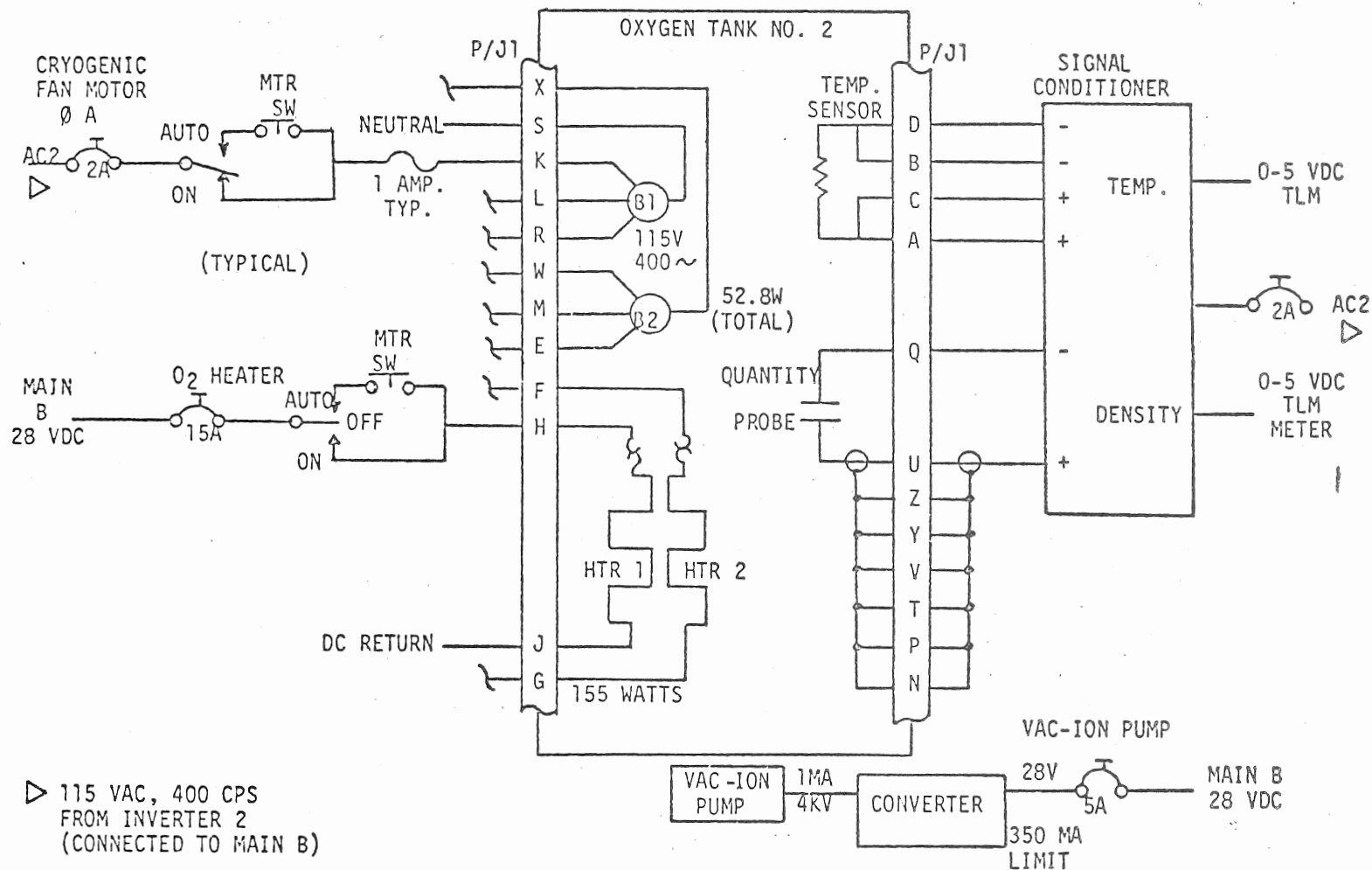
1. MSC APOLLO INVESTIGATION TEAM PANEL 1, PRELIMINARY REPORT, DATED APRIL 1970
2. APOLLO 13 UNPUBLISHED FLIGHT DATA, AVAILABLE AT NASA/MSC BUILDING 45, 3RD FLOOR, DATA ROOM
3. NASA/MSC TPS 13-T-58, IGNITION OF DESTRATIFICATION MOTOR TEST
4. MSC APOLLO INVESTIGATION TEAM PANEL 1, APOLLO 13 CRYOGENIC OXYGEN TANK 2 ANOMALY REPORT (INTERIM DRAFT), DATED MAY 22, 1970
5. NASA/MSC TPS 13-T-53, HEATER ASSEMBLY TEMPERATURE PROFILE
6. NASA/MSC TPS 13-T-59, OXYGEN TANK IGNITION SIMULATION

LIST OF ABBREVIATIONS

AL.	-	ALUMINUM
ASSY	-	ASSEMBLY
CAP	-	CAPABILITY
CRYO	-	CRYOGENIC
CU	-	COPPER
ECS	-	ENVIRONMENTAL CONTROL SYSTEM
ELEC	-	ELECTRICAL
EOI	-	EARTH ORBIT INSERTION
EPS	-	ELECTRICAL POWER SYSTEM
FAB	-	FABRICATION
FC	-	FUEL CELL
FIG.	-	FIGURE
GEN	-	GENERATE OR GENERATED
H ₂	-	HYDROGEN
H ₂ O	-	WATER
MECH	-	MECHANICAL
MSC	-	MANNED SPACECRAFT CENTER
NASA	-	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NEG.	-	NEGATIVE
NO.	-	NUMBER
O ₂	-	OXYGEN
OS-X	-	OXYGEN SUPPLY CONNECTION 1, 2 OR 3
PARA.	-	PARAGRAPH
PRELIM.	-	PRELIMINARY
PRESS	-	PRESSURE OR PRESSURIZED
QTY	-	QUANTITY
REF.	-	REFERENCE
RF	-	RADIO FREQUENCY
S/C	-	SPACECRAFT
SM	-	SERVICE MODULE
STRUCT	-	STRUCTURE OR STRUCTURAL
SYS	-	SYSTEM
TEMP	-	TEMPERATURE

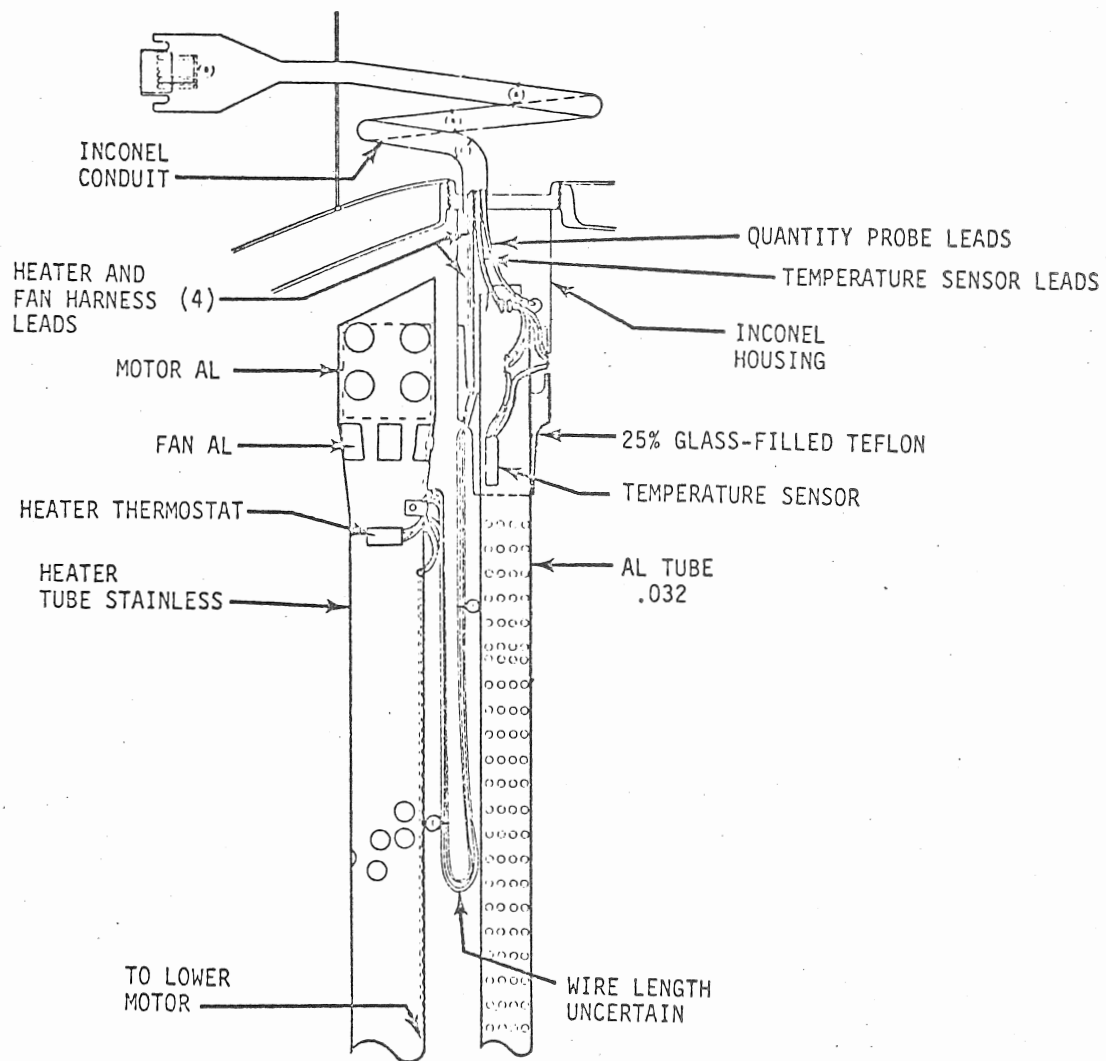
SIMPLIFIED SCHEMATIC OF EPS
AND CRYOGENIC OXYGEN SYSTEM

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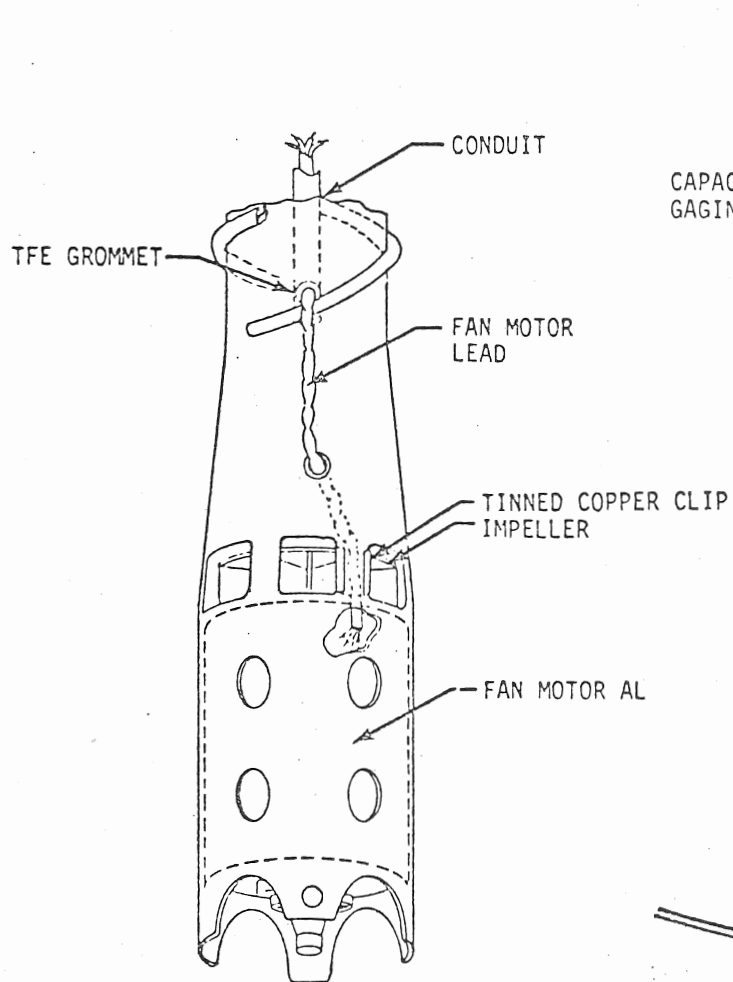
OXYGEN TANK NO. 2 ELECTRICAL SCHEMATIC

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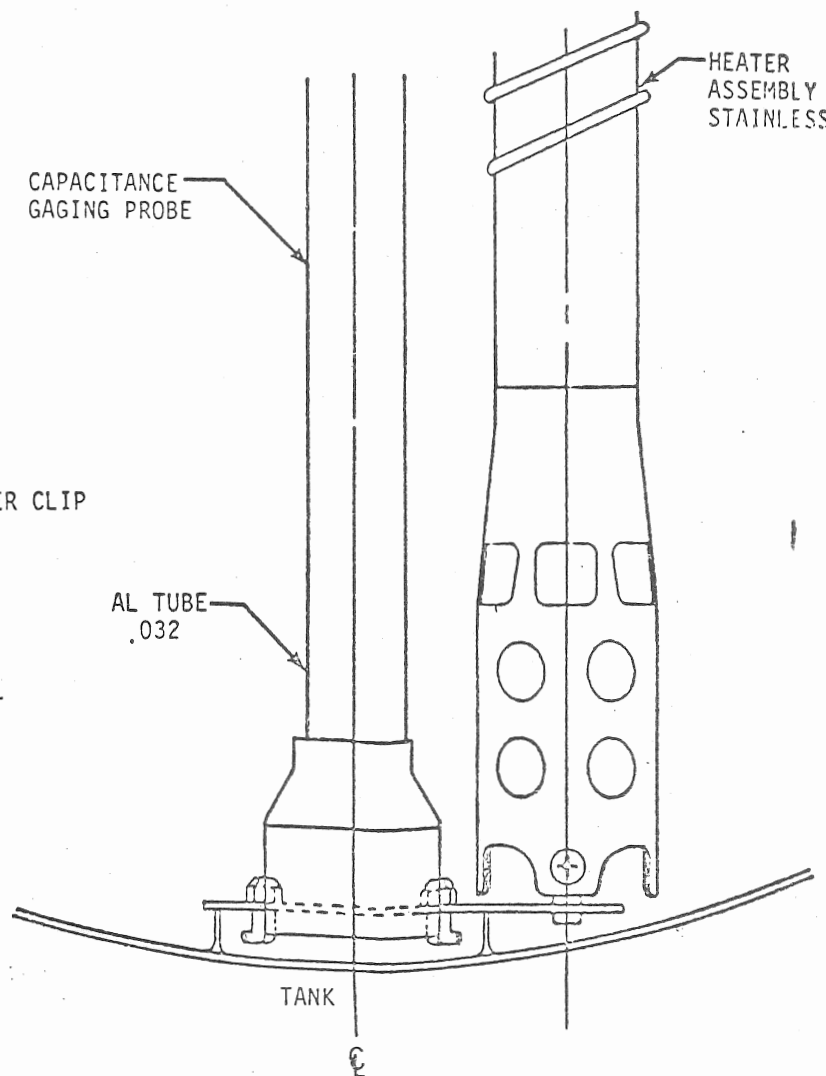


UPPER HEATER AND PROBE ASSEMBLY

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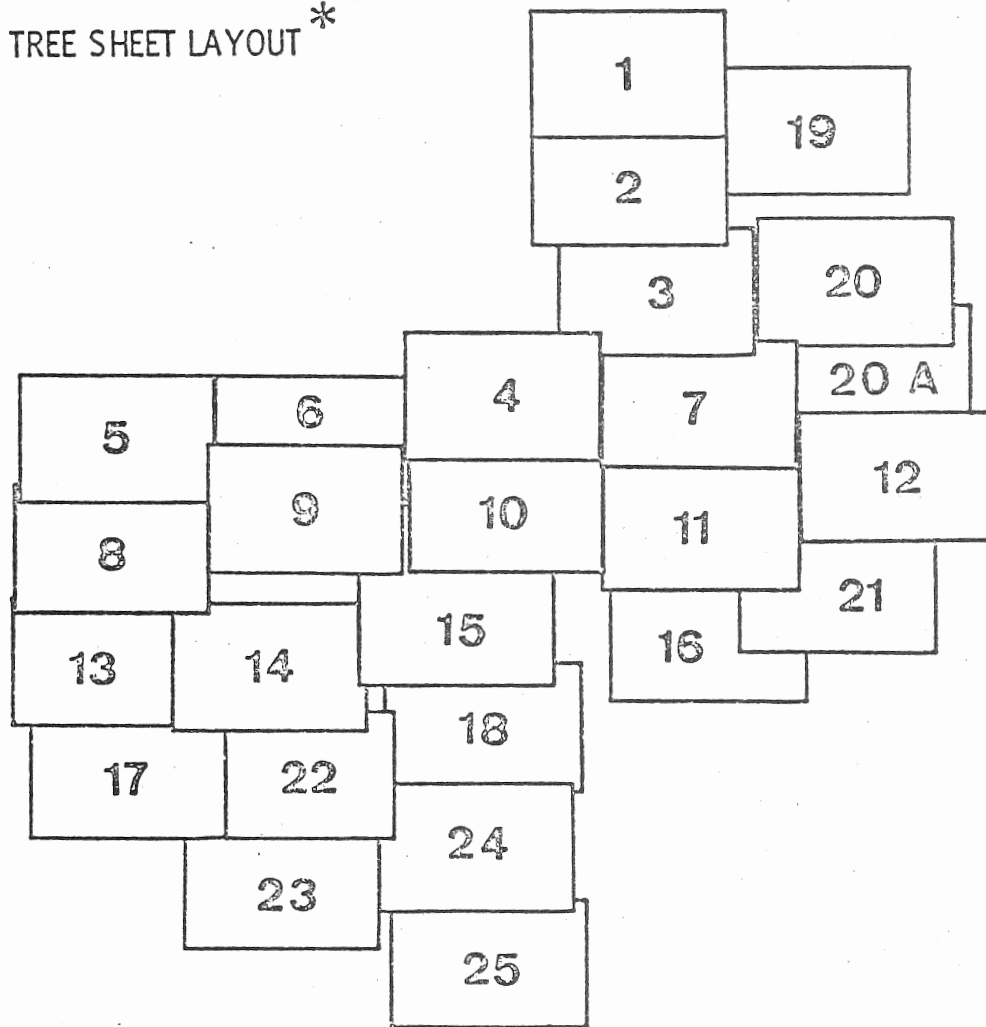


DETAIL OF HEATER
ASSEMBLY



LOWER HEATER AND PROBE ASSEMBLY

FAULT TREE SHEET LAYOUT *



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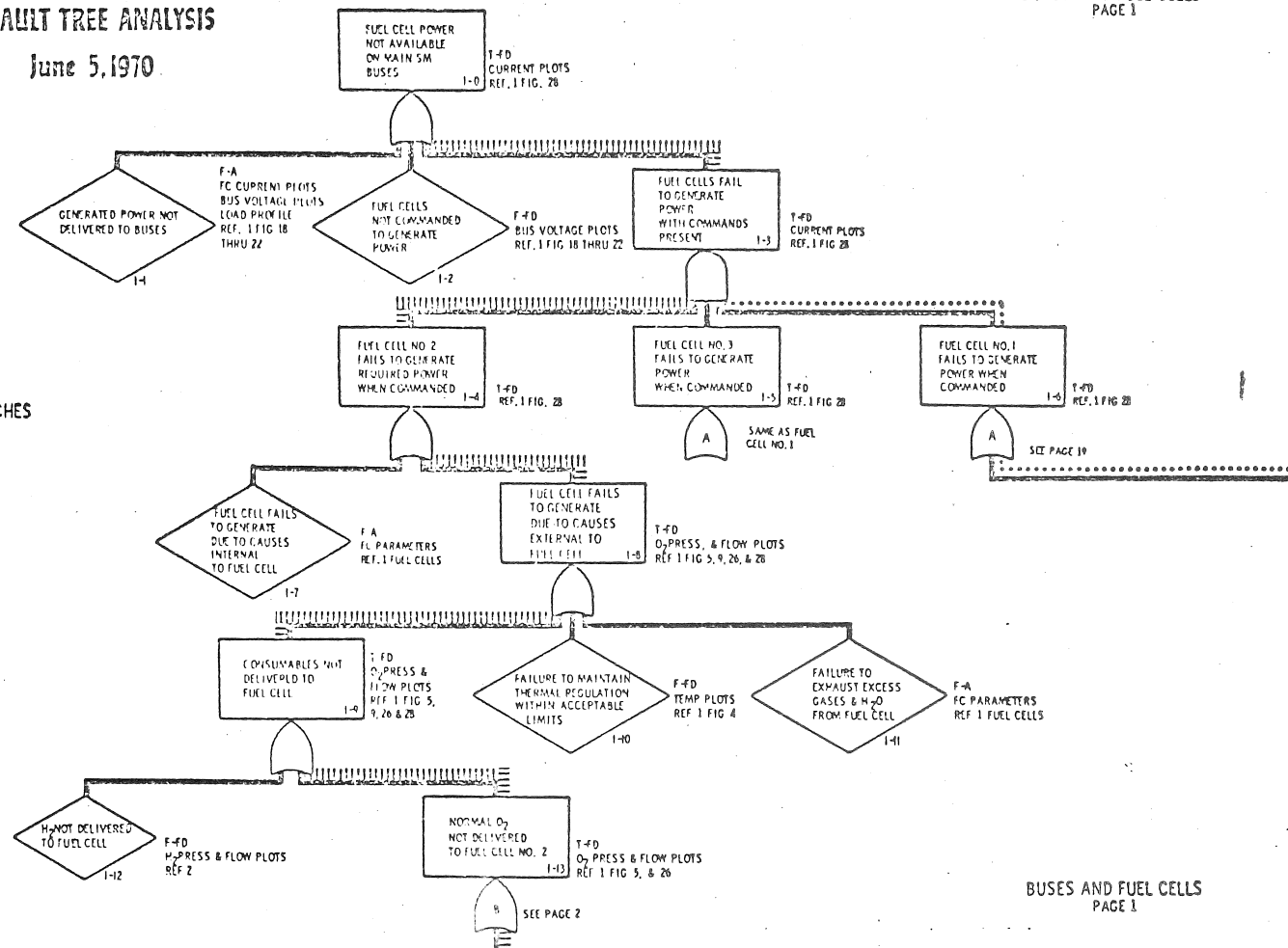
* TO ASSEMBLE FAULT TREE, LAYOUT PAGES IN THE POSITIONS SHOWN ABOVE

FAULT TREE ANALYSIS

June 5, 1970

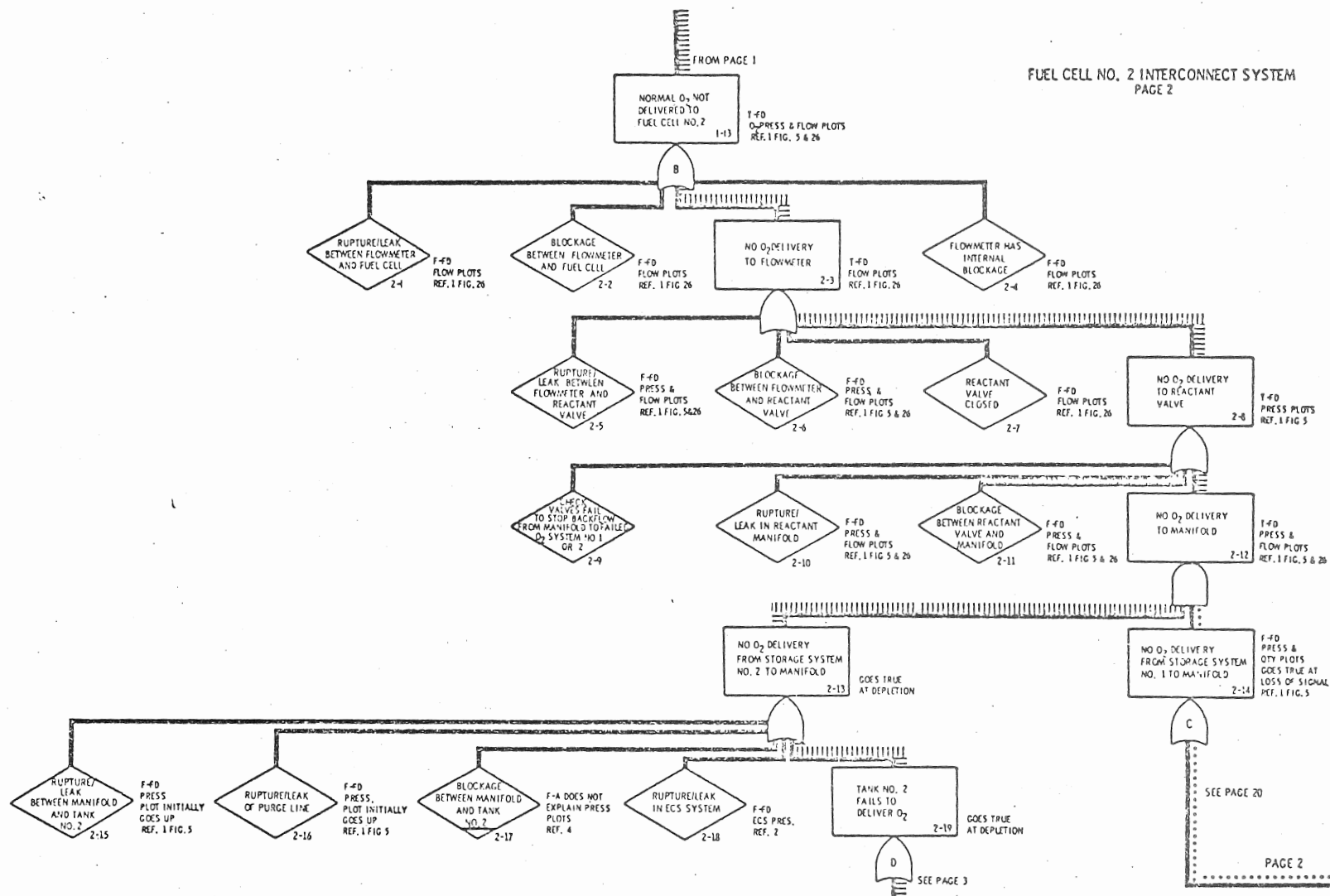
BUSES AND FUEL CELLS
PAGE 1

||||| MAIN THREAD
..... CONTRIBUTORY BRANCHES

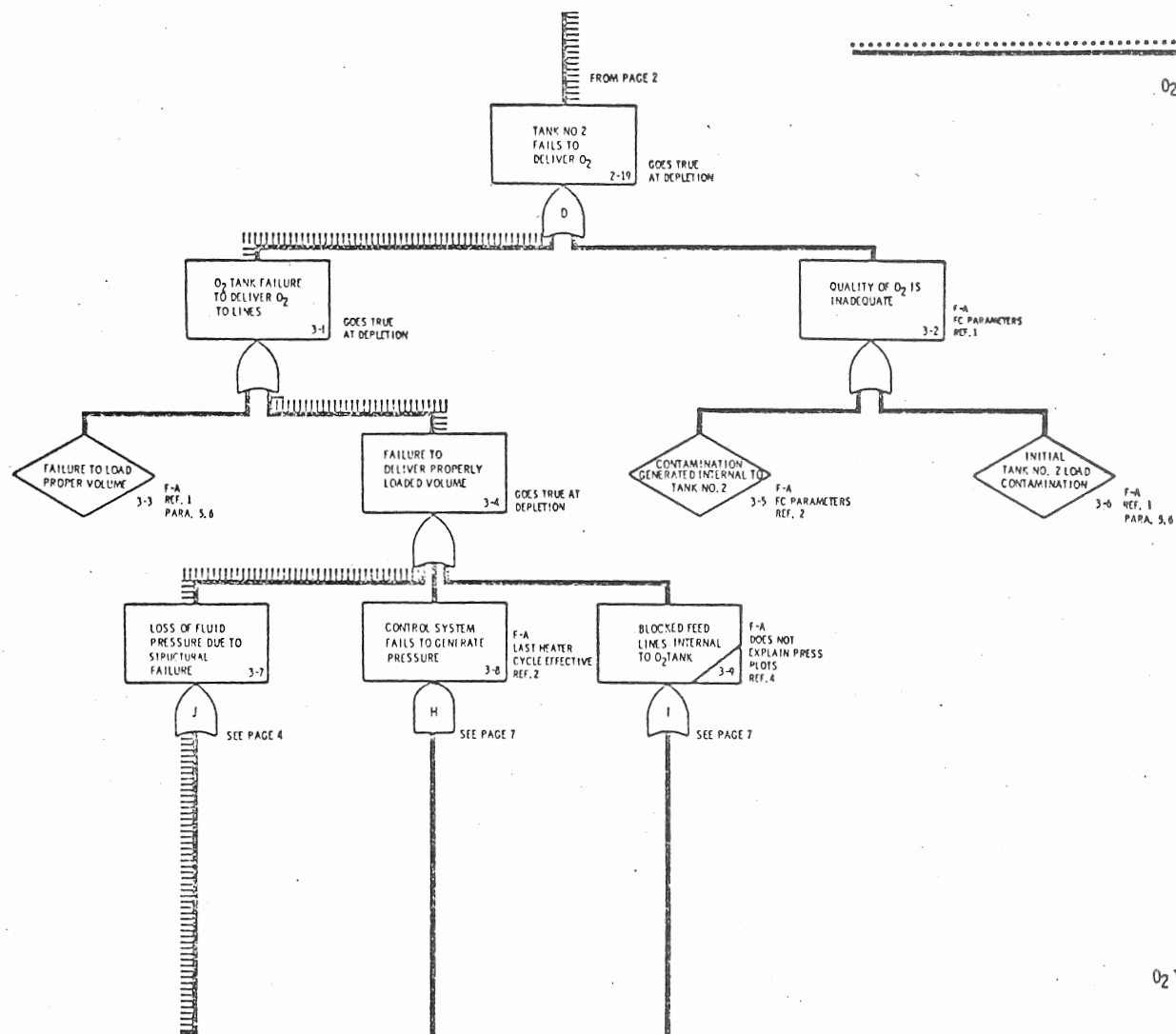


BUSES AND FUEL CELLS
PAGE 1

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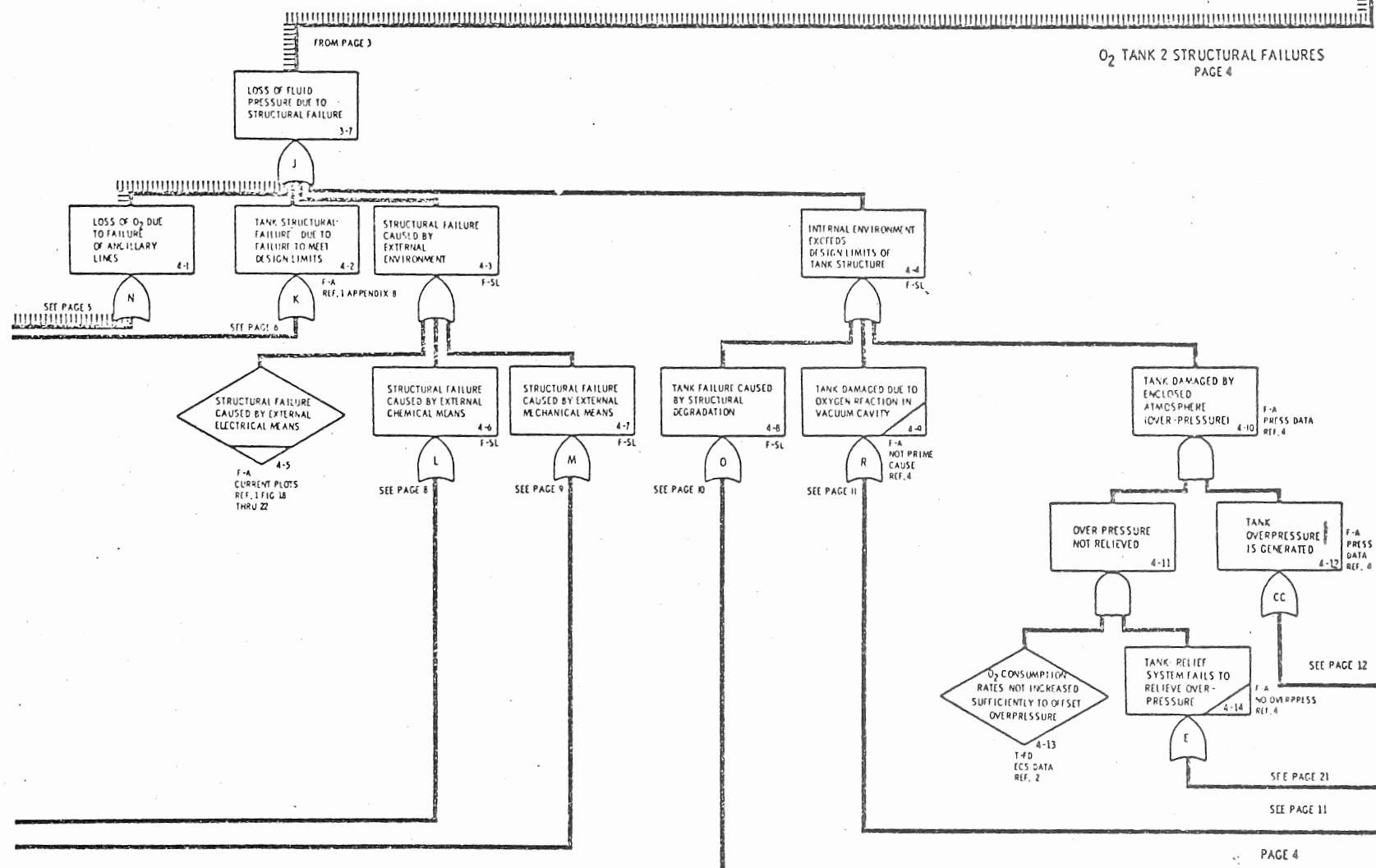
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O₂ TANK NO. 2
PAGE 3

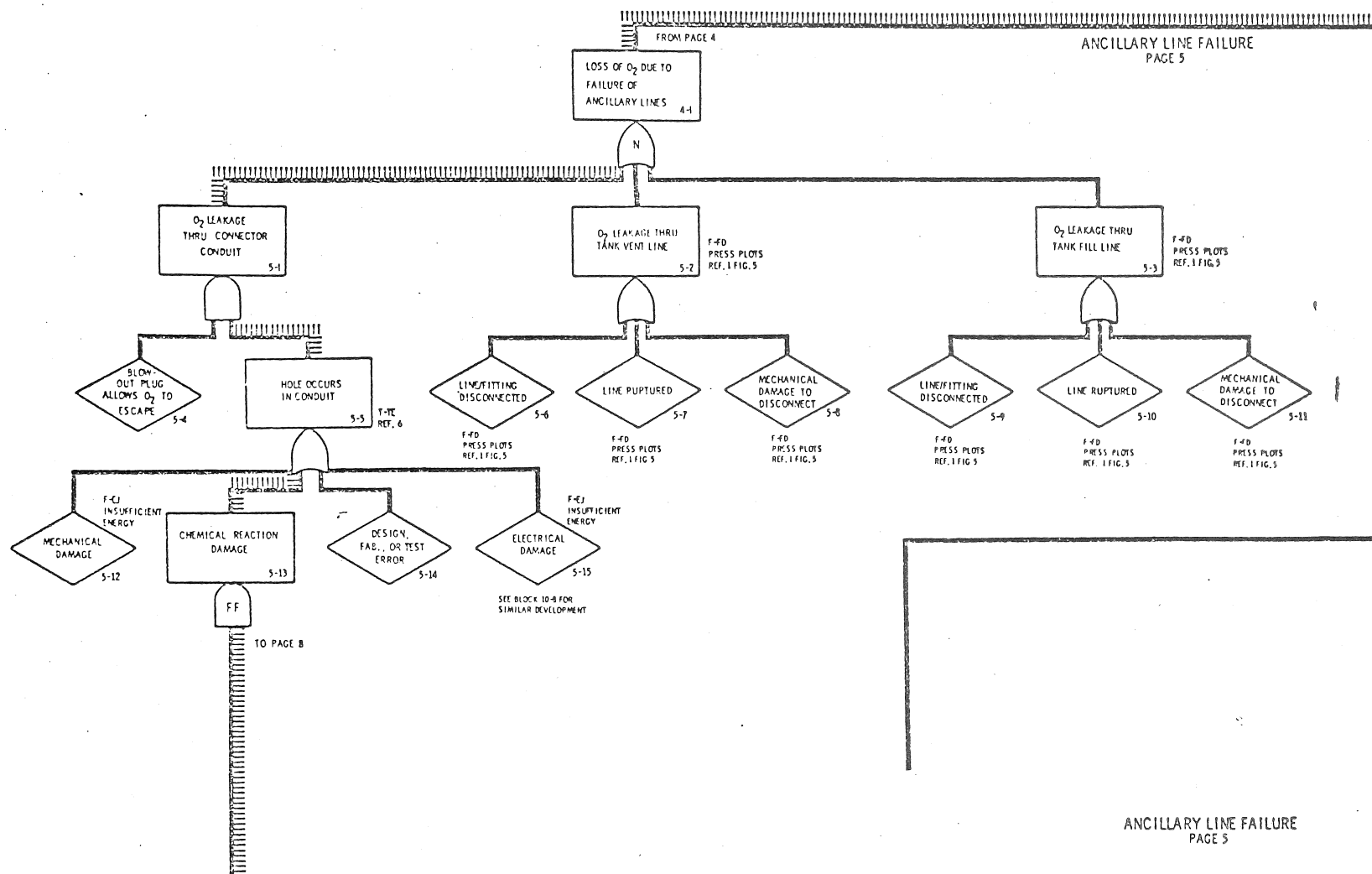
O₂ TANK NO. 2
PAGE 3

O₂ TANK 2 STRUCTURAL FAILURES
PAGE 4



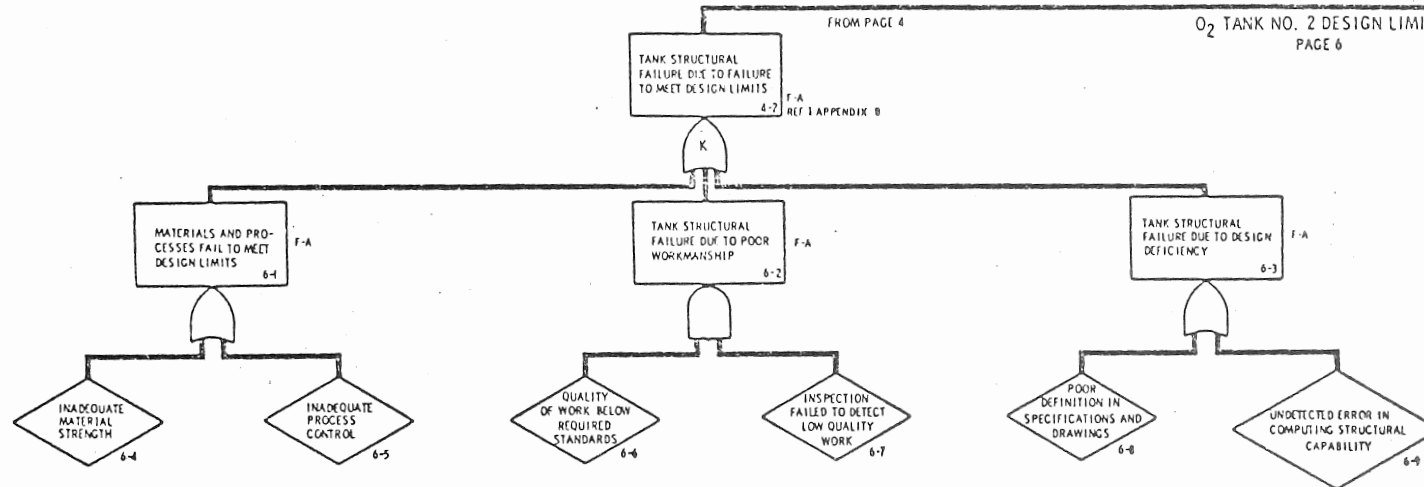
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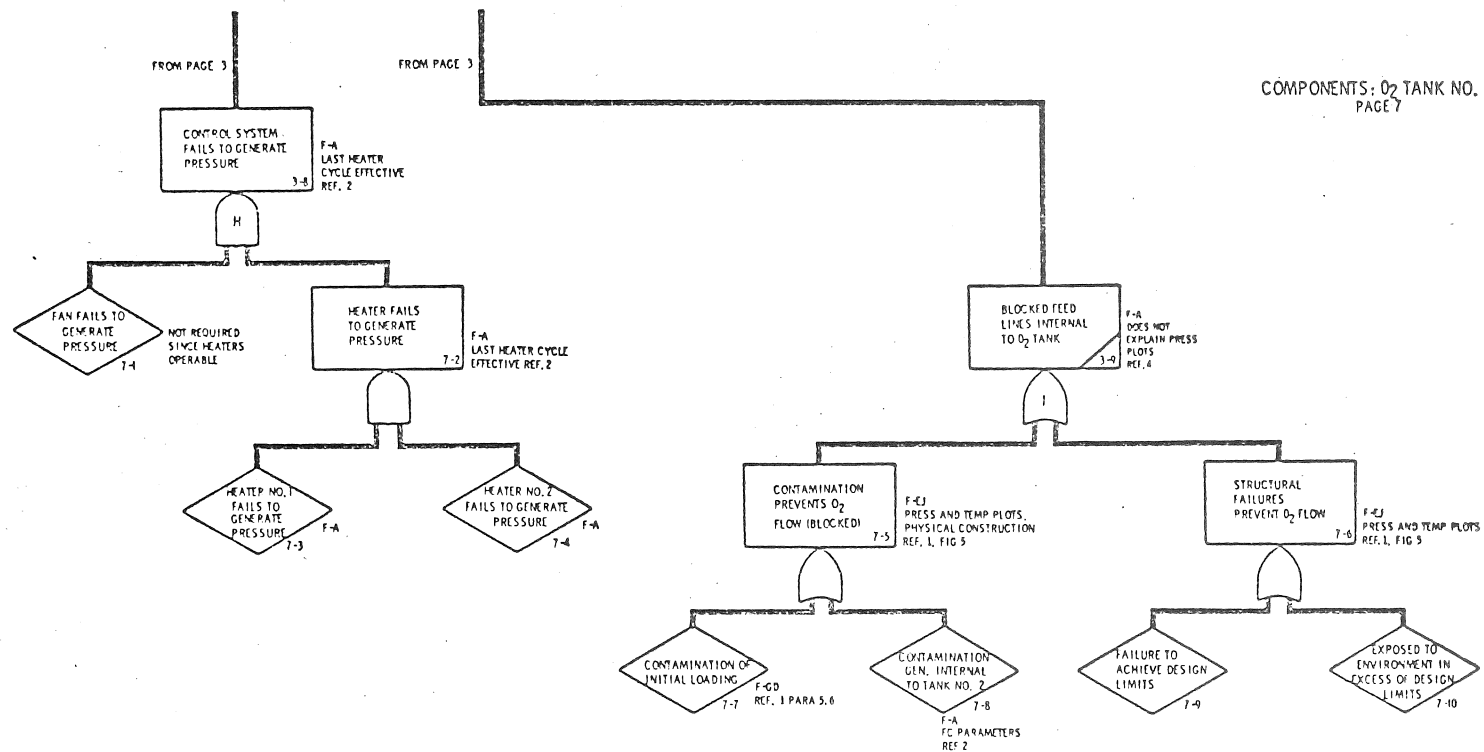
O₂ TANK NO. 2 DESIGN LIMITS
PAGE 6



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O₂ TANK NO. 2 DESIGN LIMITS
PAGE 6

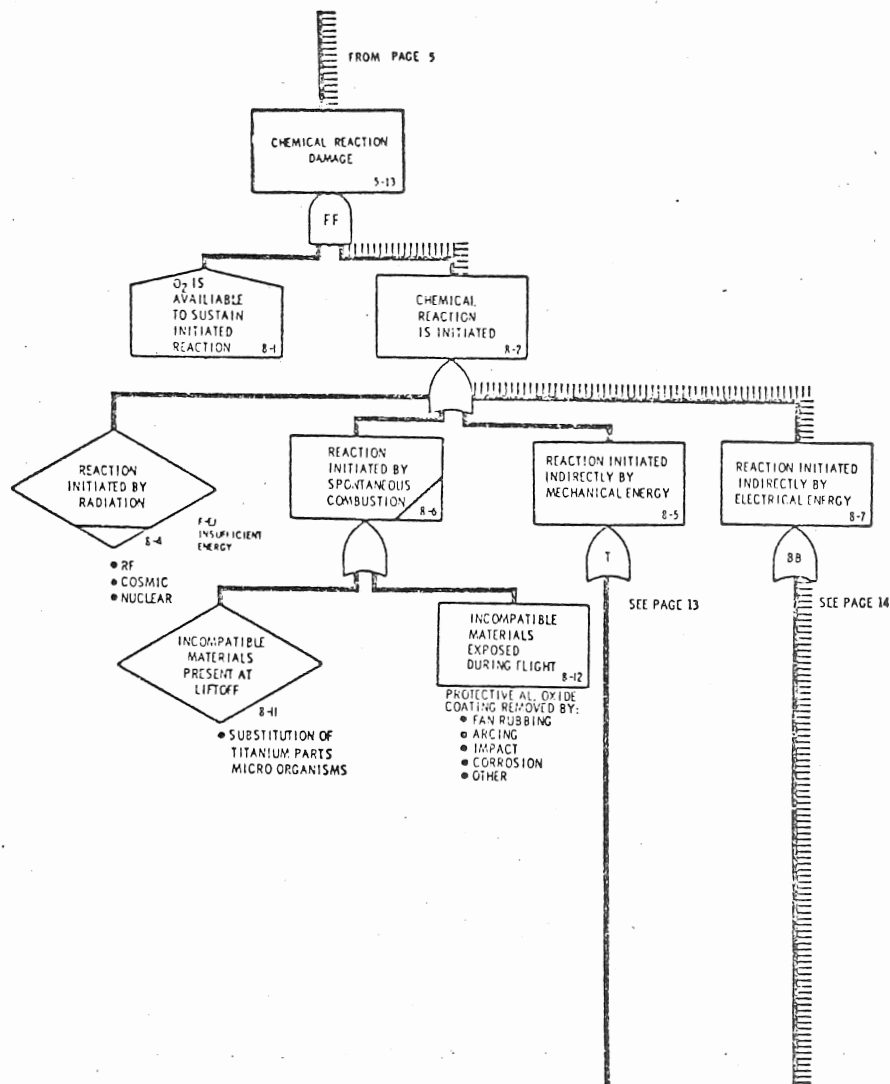
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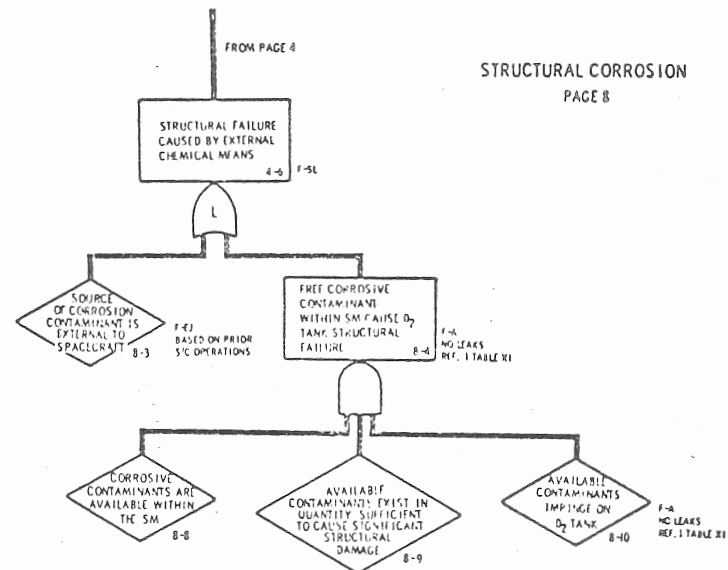
COMPONENTS: O₂ TANK NO. 2
PAGE 7

COMPONENTS: O₂ TANK NO. 2
PAGE 7

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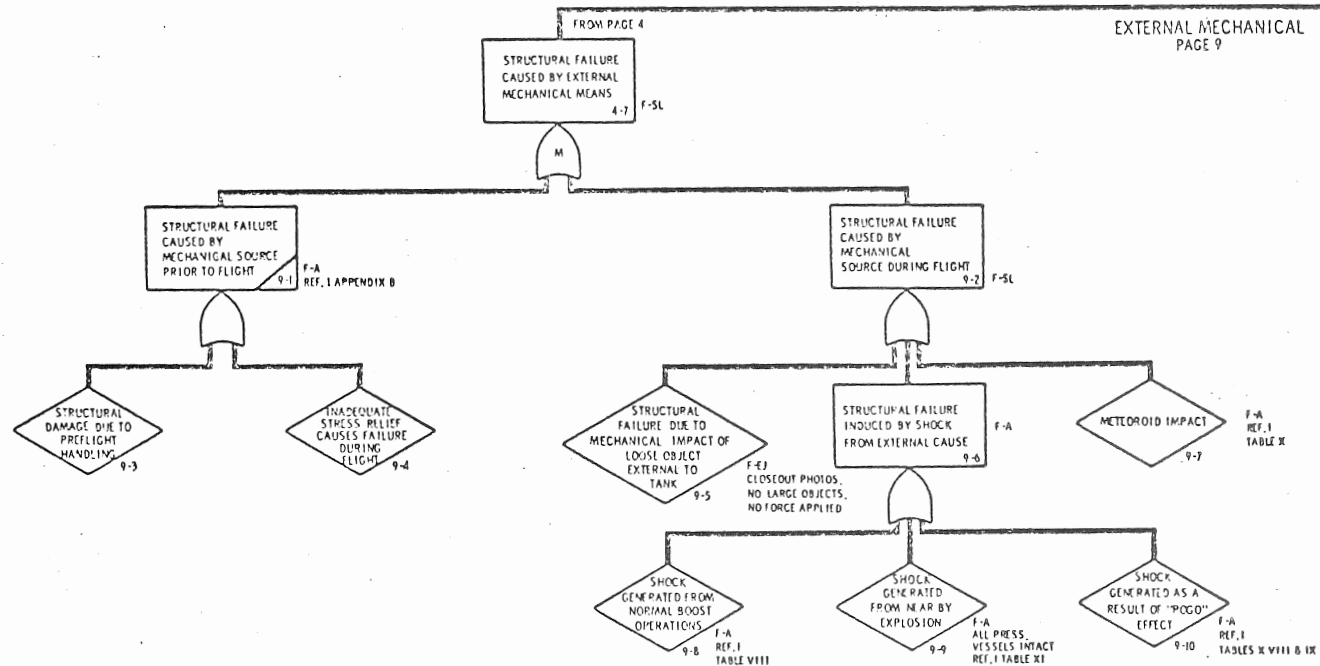


STRUCTURAL CORROSION PAGE 8

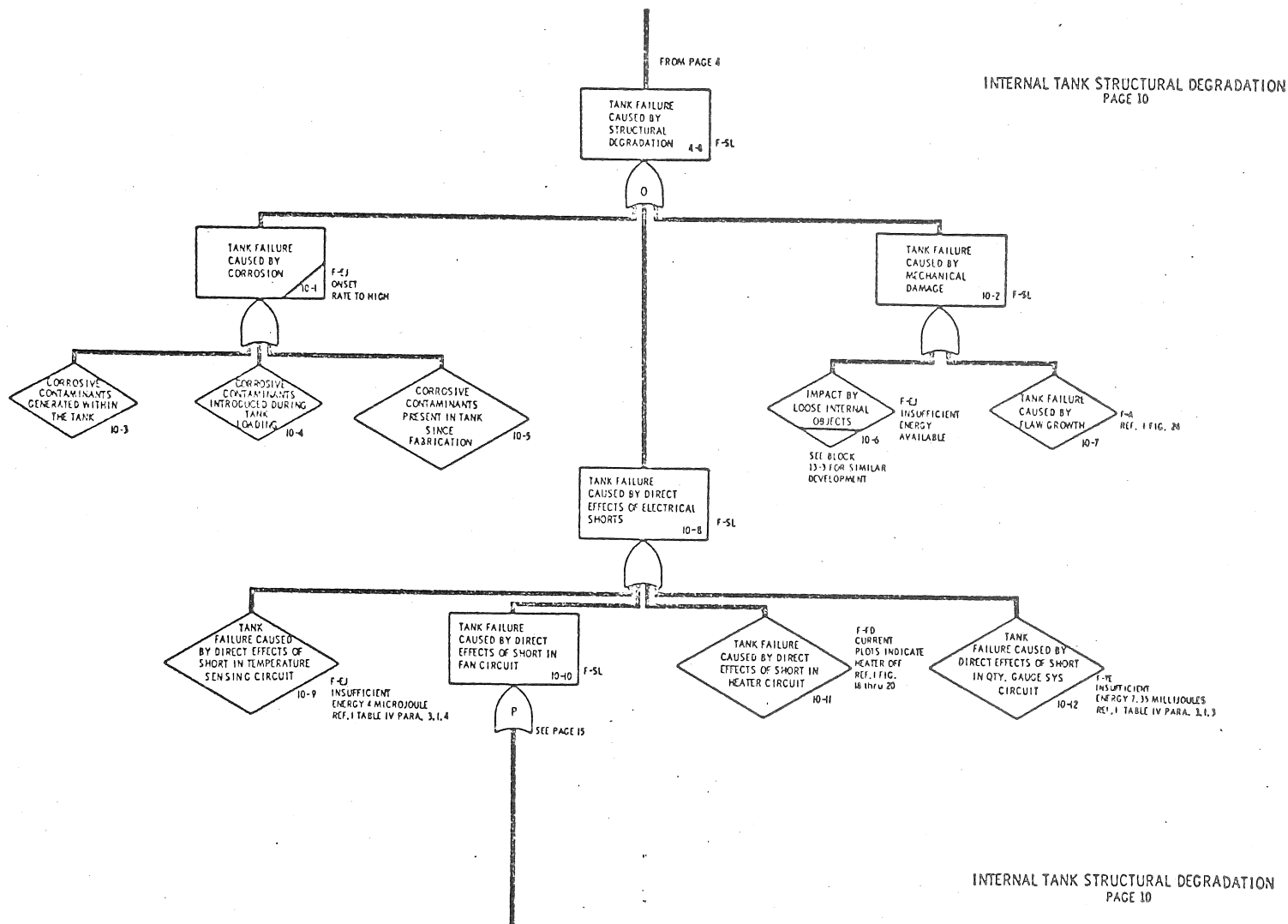


STRUCTURAL CORROSION PAGE 8

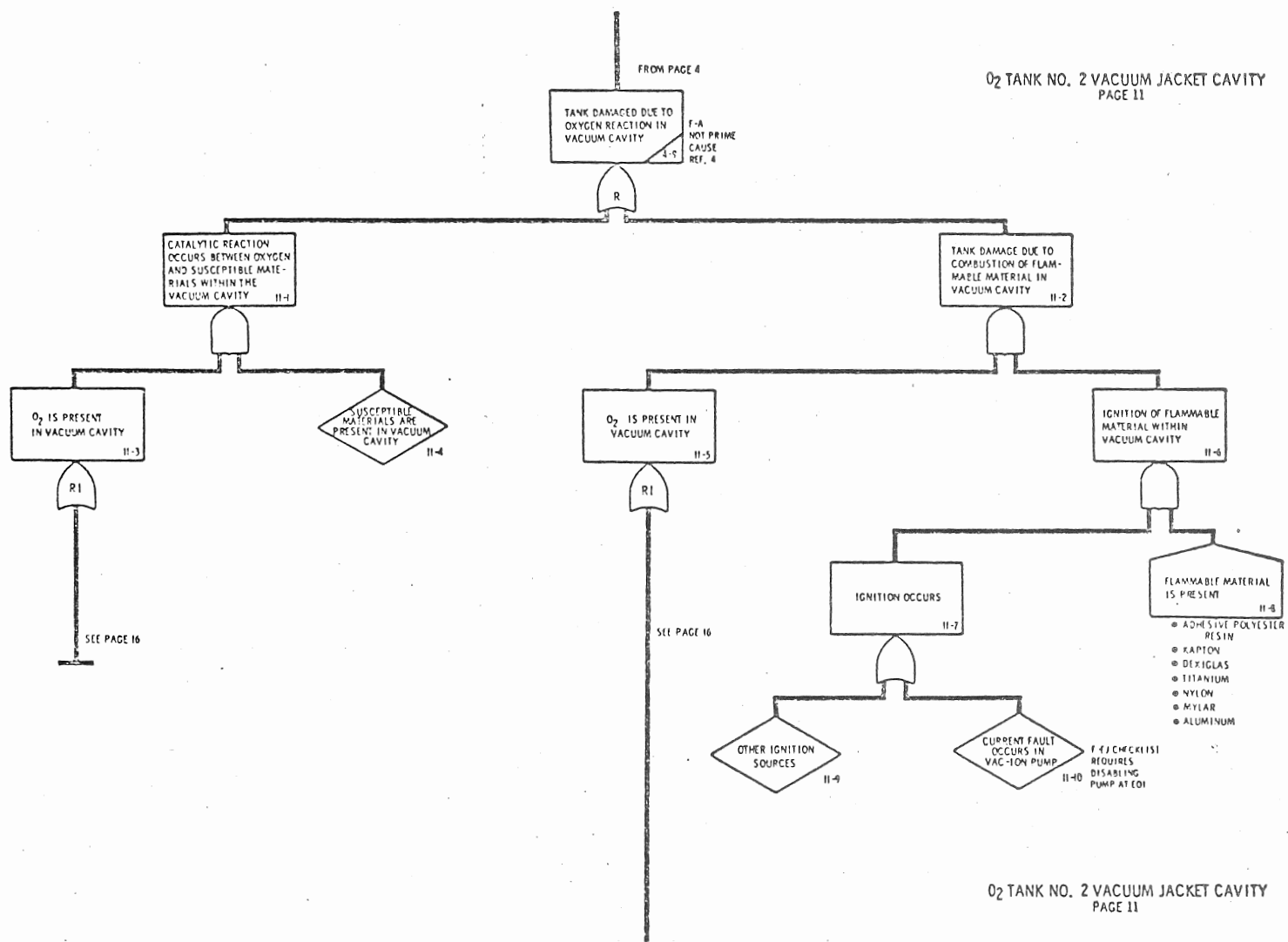
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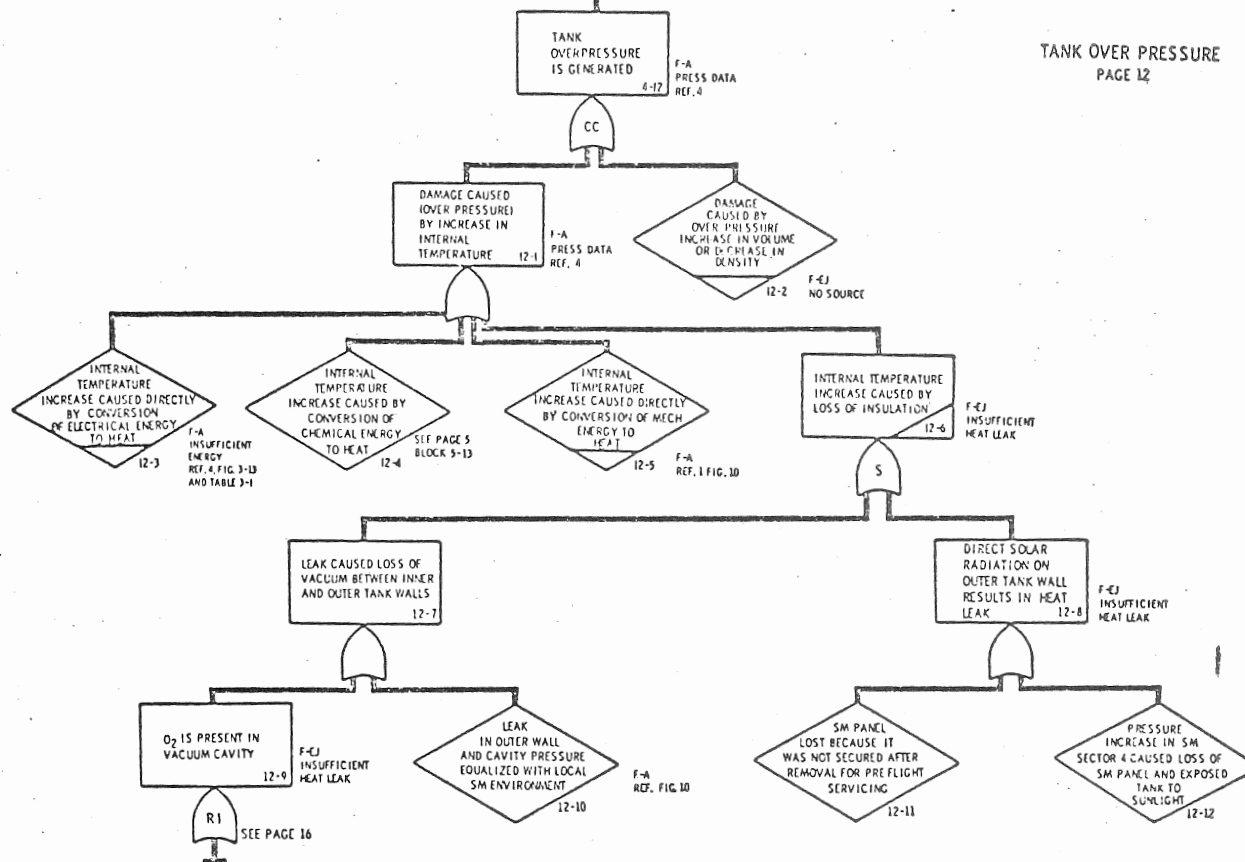


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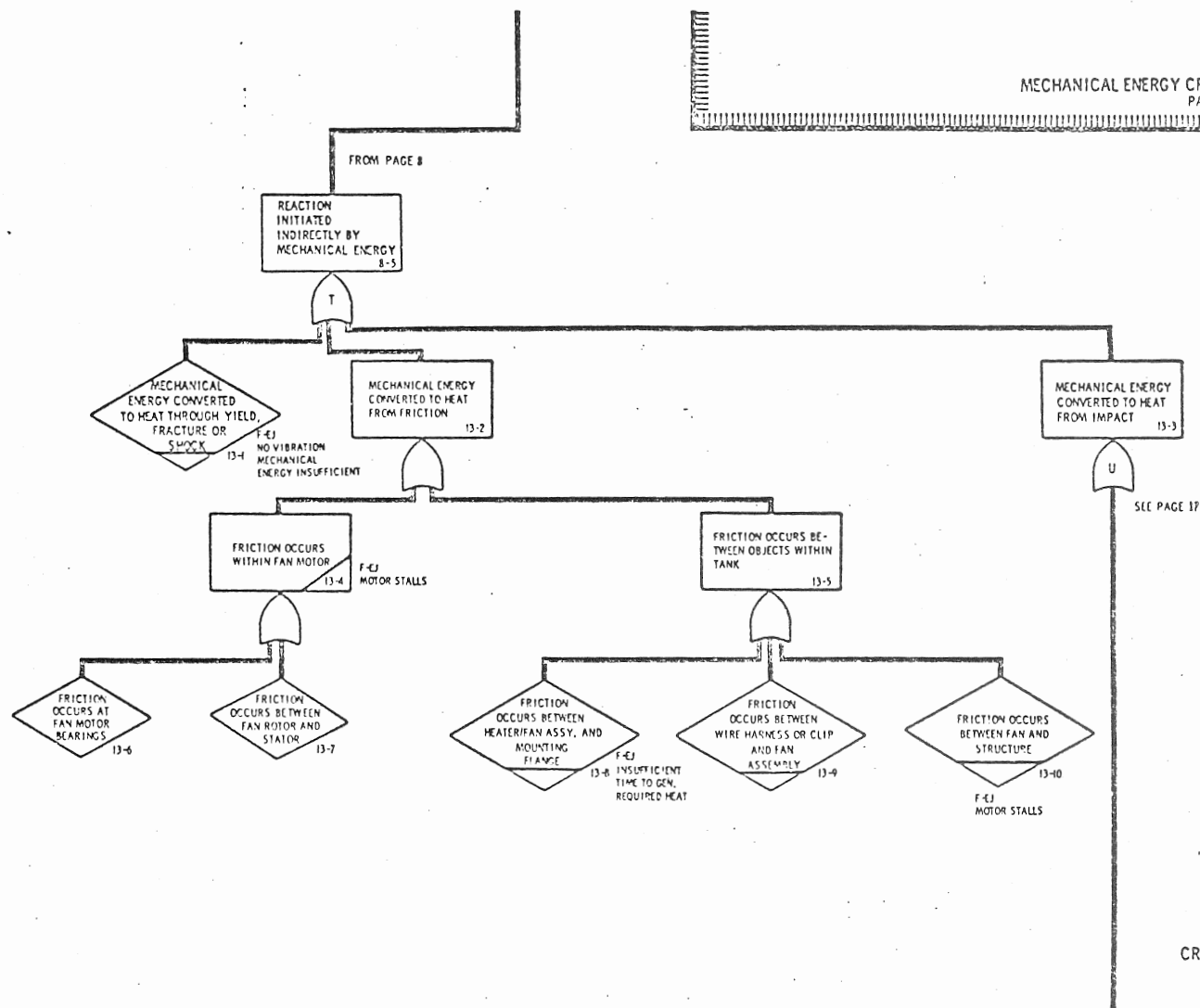
TANK OVER PRESSURE PAGE 12



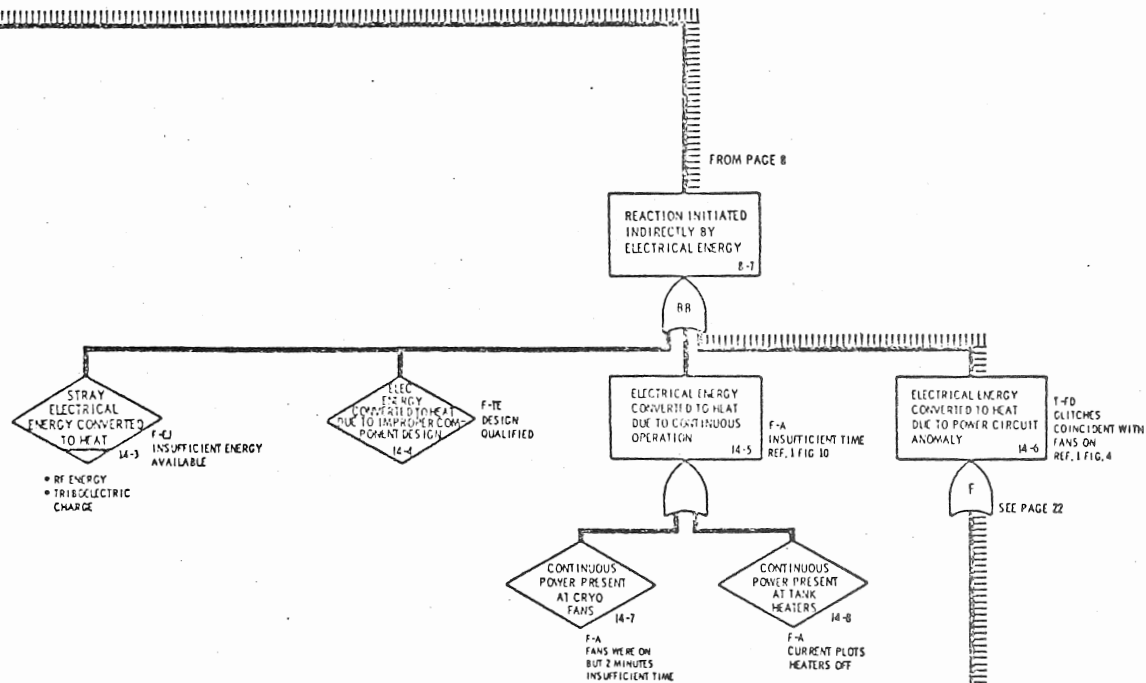
TANK OVER PRESSURE PAGE 12

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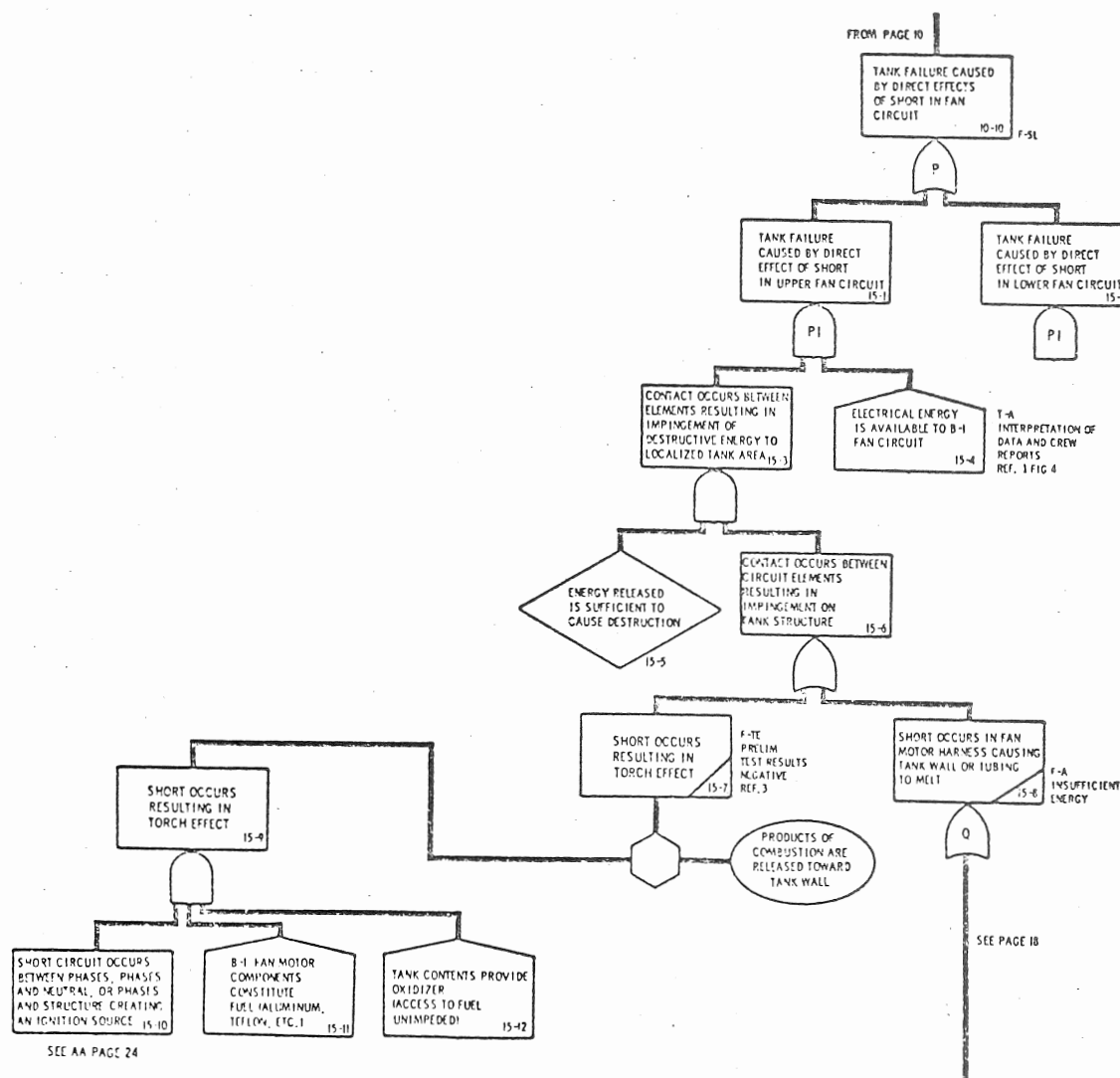


MECHANICAL ENERGY
CREATES HEAT IN O₂ TANK 2
PAGE 13



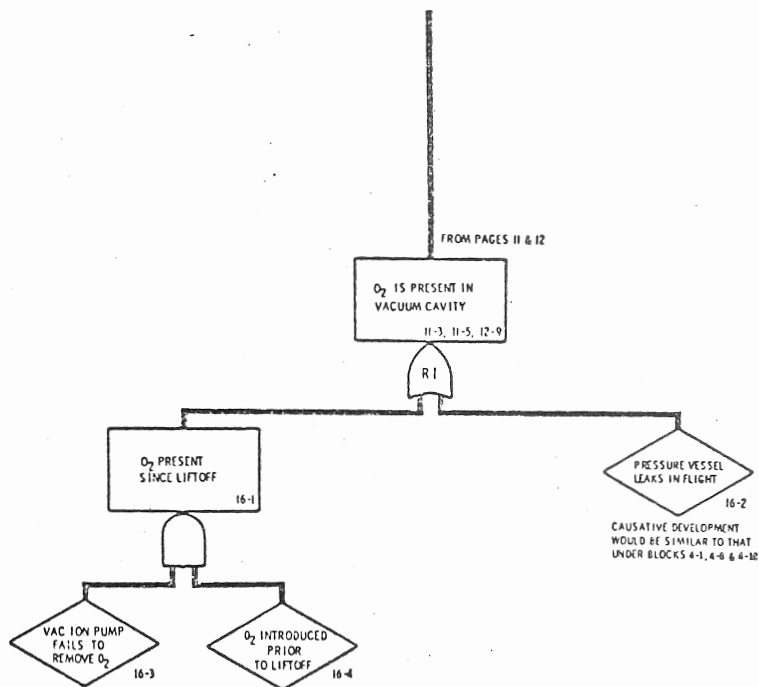
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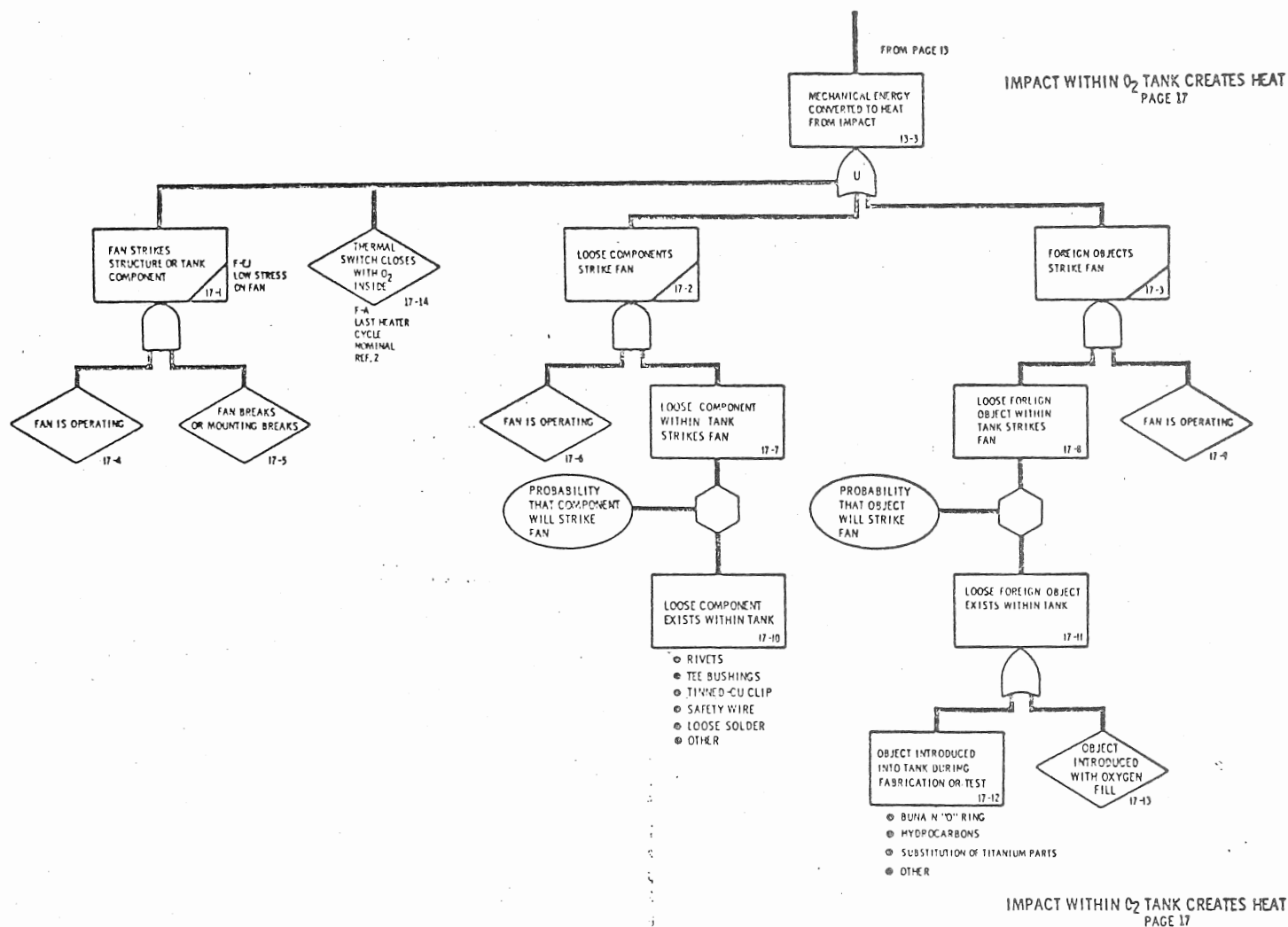


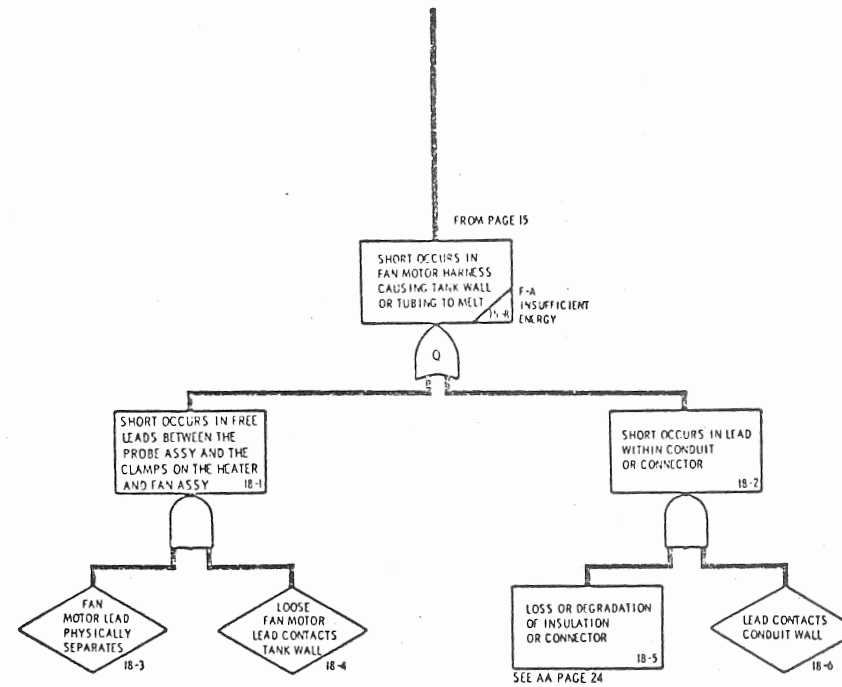
FANS MOTOR SHORT-TORCH EFFECT
PAGE 15

FANS MOTOR SHORT-TORCH EFFECT
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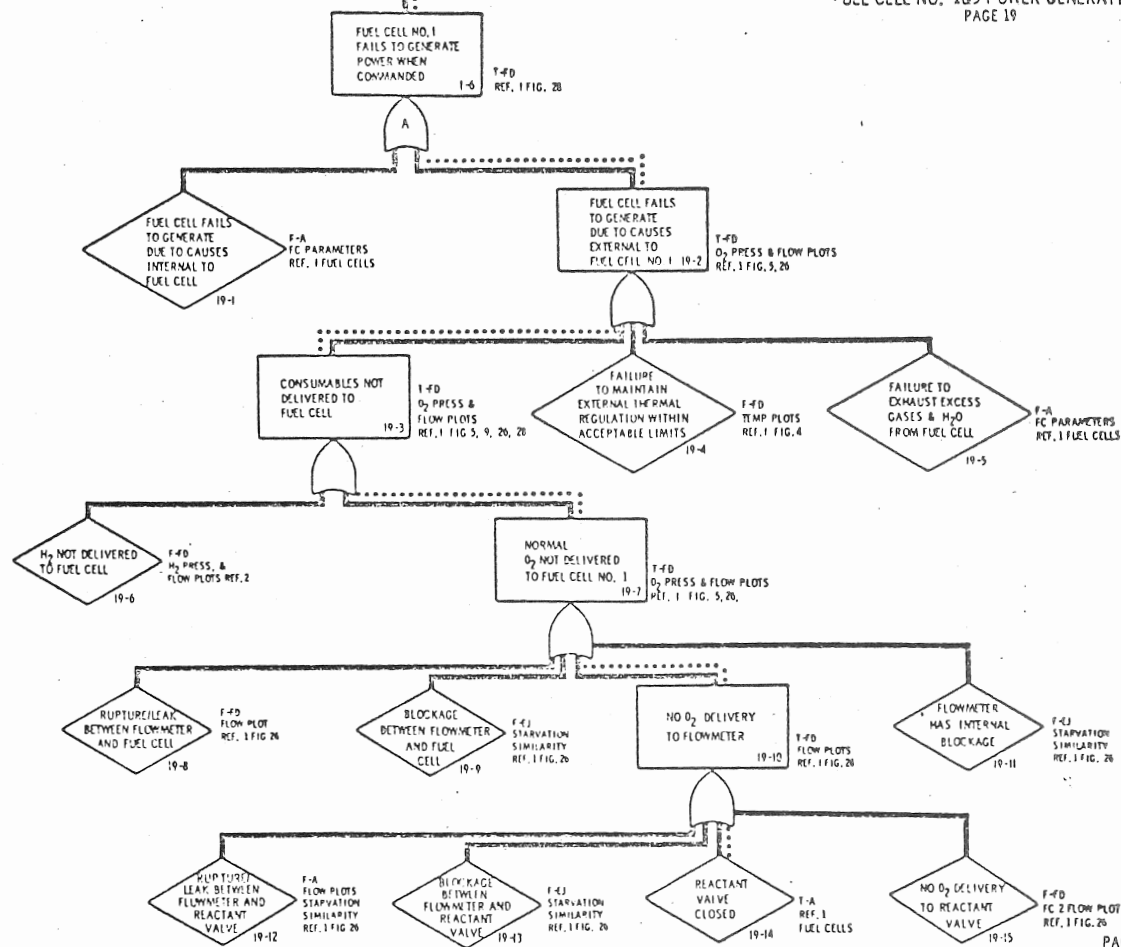


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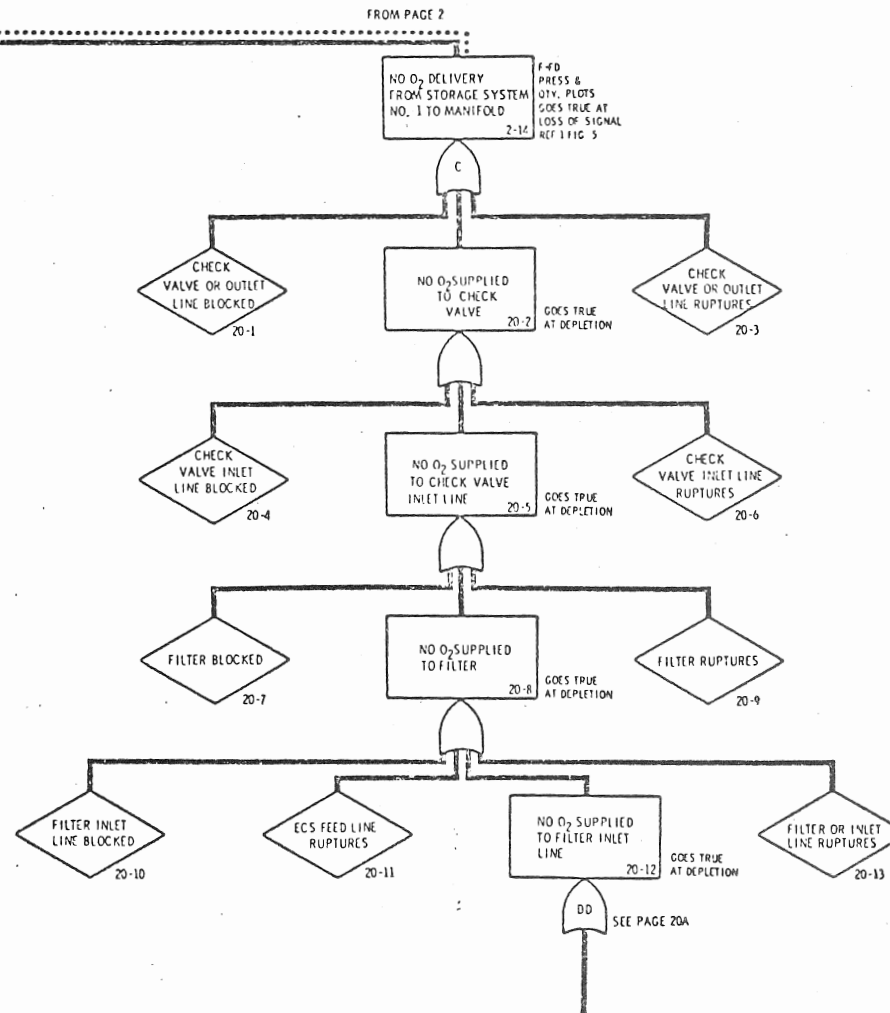
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FUEL CELL NO. 1 & 3 POWER GENERATION PAGE 19



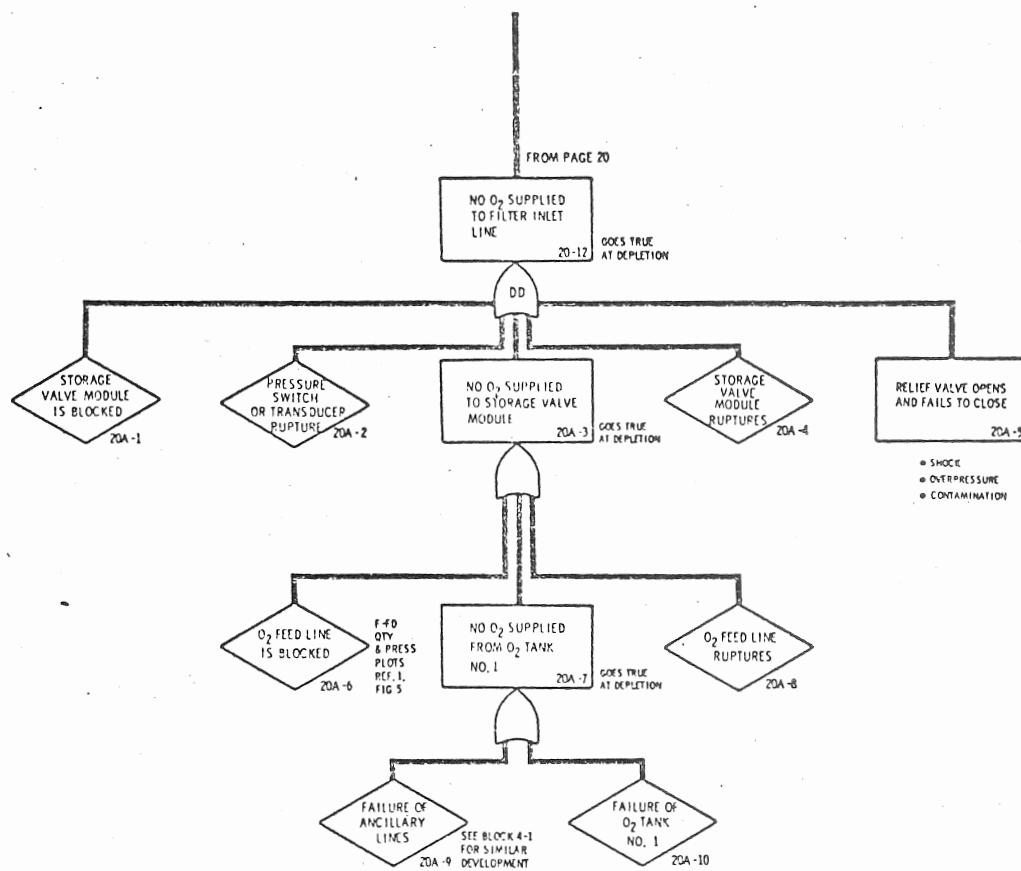
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O₂ STORAGE SYSTEM NO. 1
PAGE 20

O₂ STORAGE SYSTEM No. 1
PAGE 20

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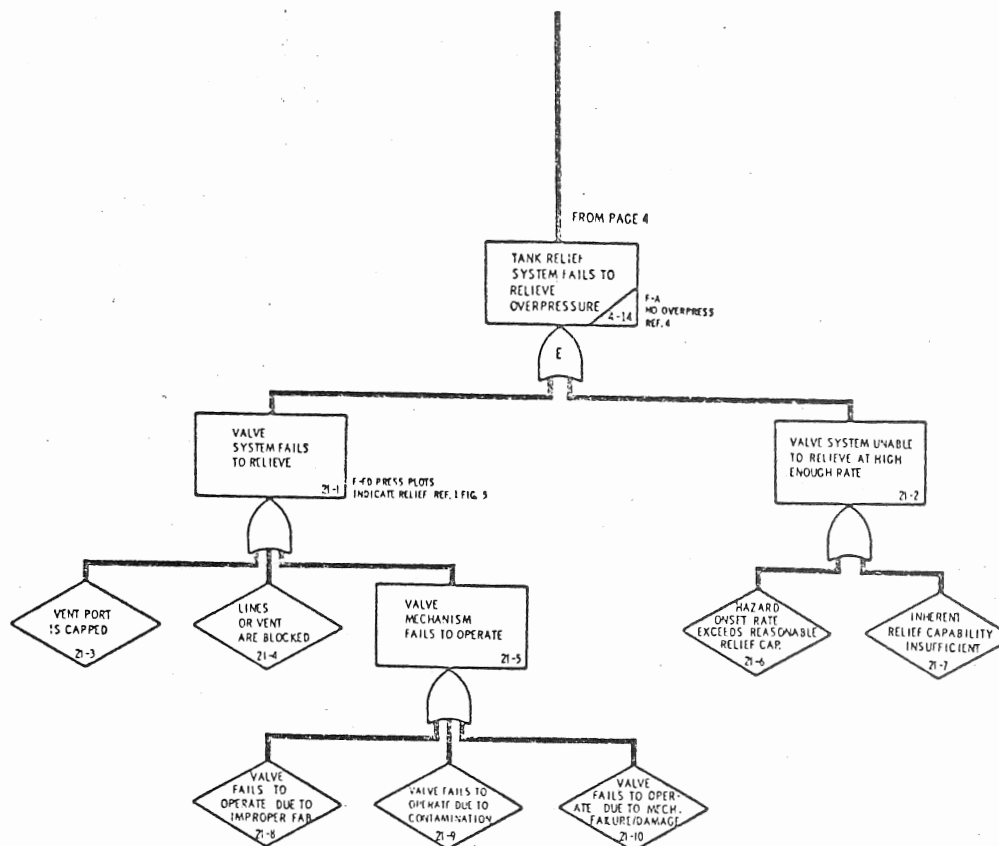


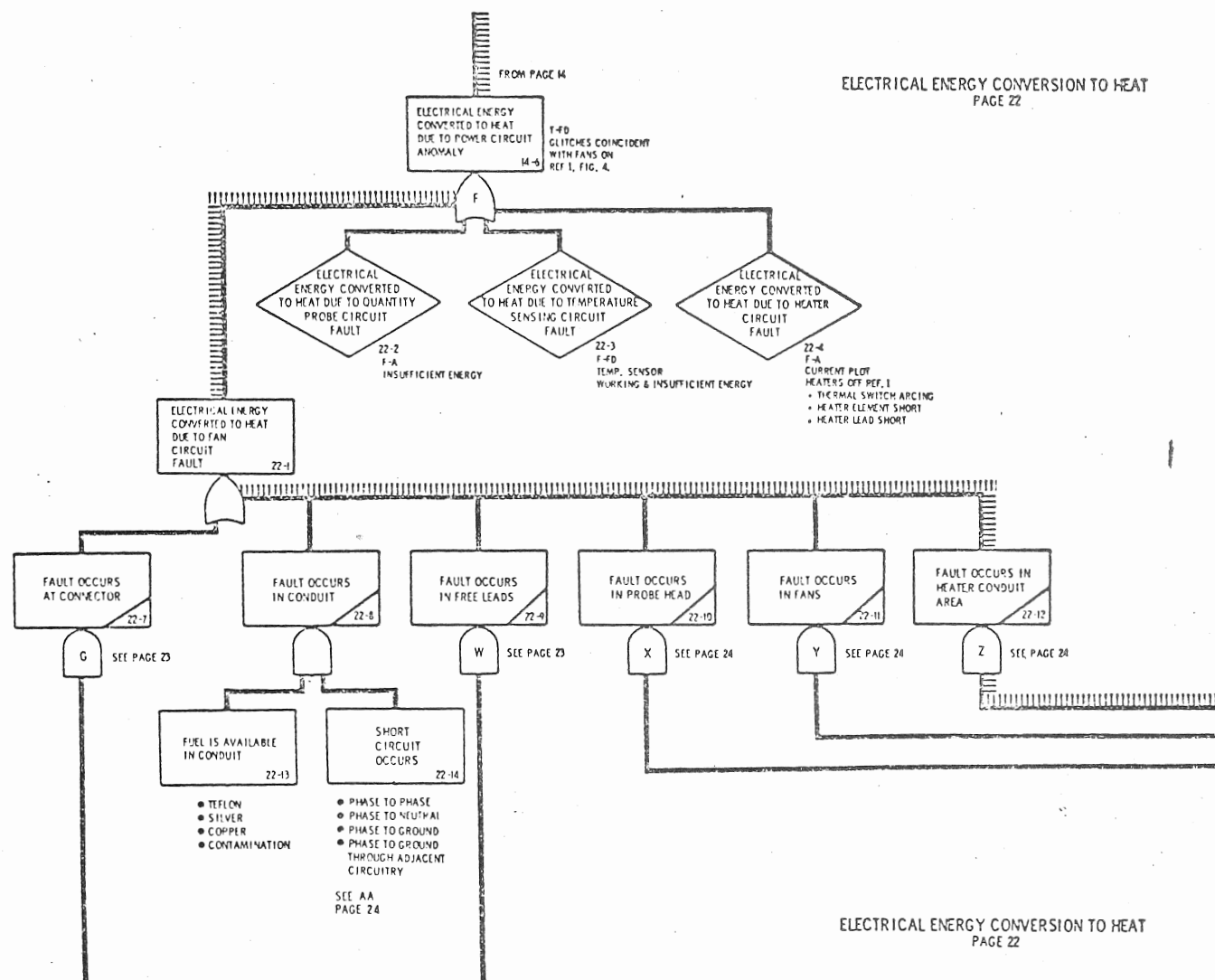
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& TANK NO. 1

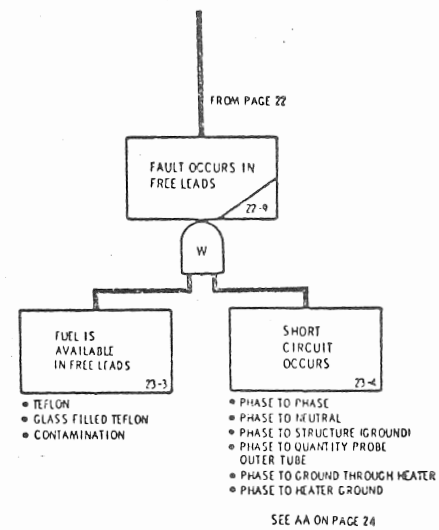
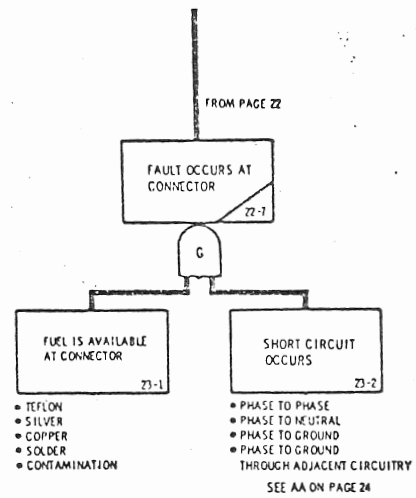
PAGE 20A

O₂ STORAGE SYSTEM No. 1
& TANK NO. 1

PAGE 20A

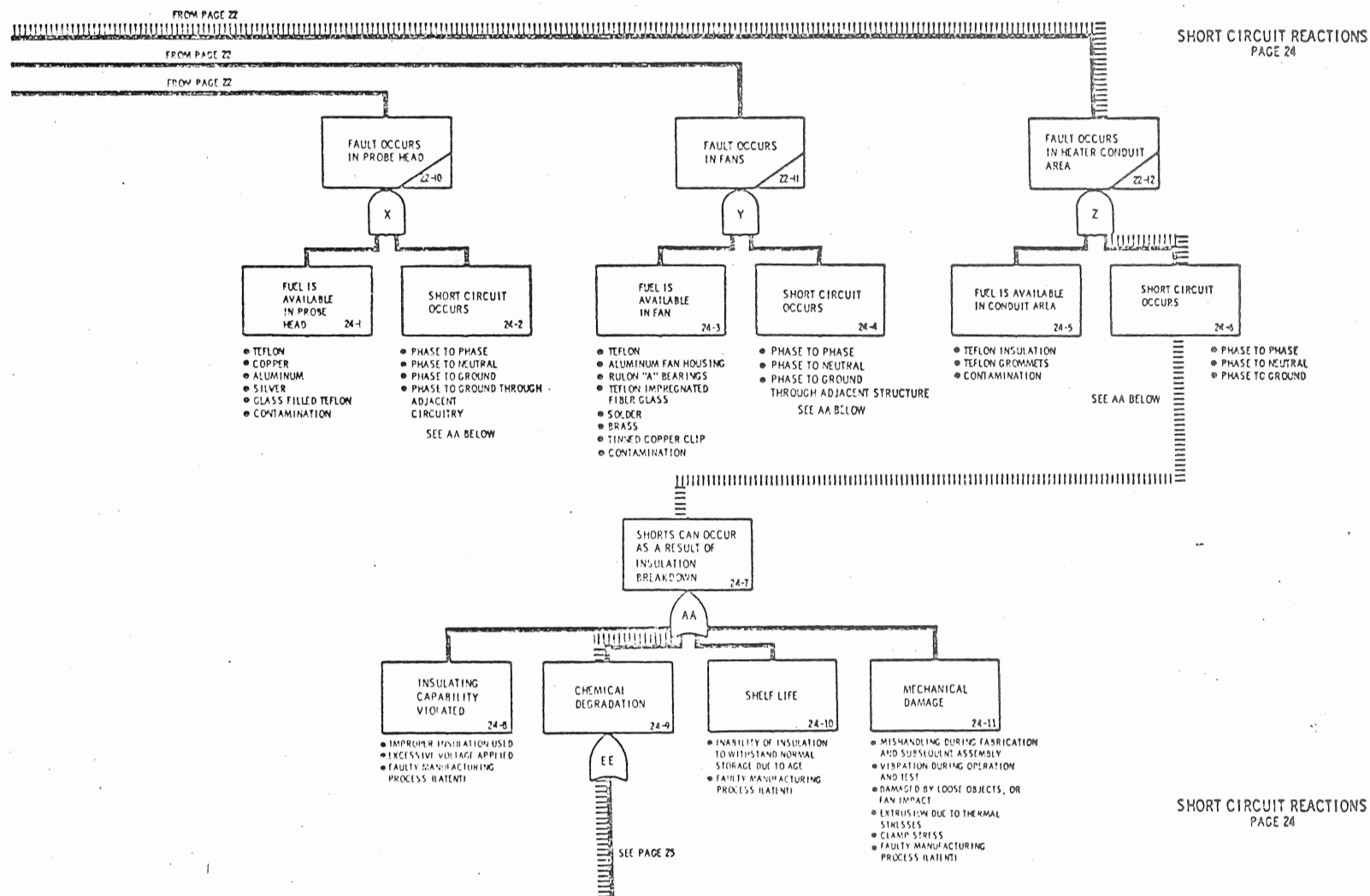


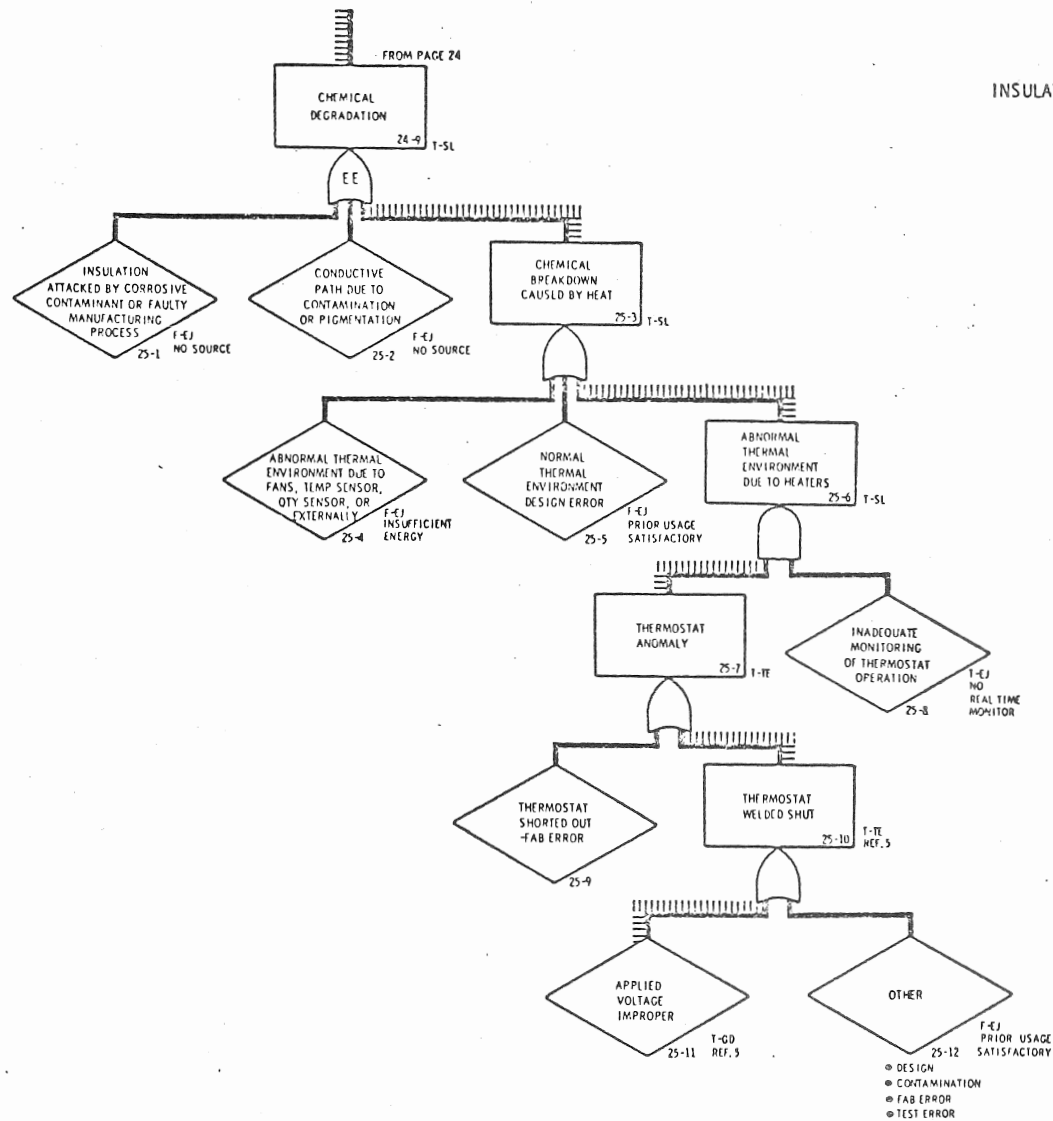




SHORT CIRCUIT REACTIONS
PAGE 23

SHORT CIRCUIT REACTIONS
PAGE 23





REFERENCES

1. Weber, Laurence A.: Thermodynamic and Related Properties of Oxygen from the Triple Point to 300° K at Pressures to 330 Atmospheres. Supplement A (British Units), NBS Report 9710A, August 29, 1968.
2. Stewart, Richard B.: The Thermodynamic Properties of Oxygen. PH.D. Thesis, Dept. of Mechanical Engineering, University of Iowa, June 1966.
3. Weber, Laurence A.: P-V-T, Thermodynamic and Related Properties of Oxygen from the Triple Point to 300 K at Pressures to 33 MN/m². Journal of Research of the National Bureau of Standards - A. Physics and Chemistry, Vol. 74A, No. 1, January-February 1970, pp. 93-129.